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VOLCANIC DUST AND OTHER FACTORS IN THE PRODUCTION OF CLIMATIC CHANGES, AND THEIR POSSIBLE RELATION TO ICE AGES.*

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INTRODUCTION.

OLD lake beaches, glacial moraines, and various other geological records give indisputable evidence of numerous climatic changes. It appears, too, that these changes were irregular in their times of occurrence and irregular also in their intensity and duration. Many seem to have been mild and relatively fleeting, while a few were so profound and lasting as even to bring on ice ages and to cover extensive areas of the earth with glacial sheets, or, on the other hand, to melt these sheets away and to establish for long periods warm and genial climates over much the greater portion of the earth.

When this series of climatic changes began there is no sure means of knowing, for the records, especially those of glacial origin, grow gradually fainter and more scanty with increase

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of geologic age, and it is probable, therefore, that the effects of many of the earlier changes have long since been completely obliterated. But, however this may be, it is well-nigh certain that from the time of the earliest known of these changes down to the very present the series has been irregularly continuous, and the end, one might reasonably assume, is not yet. Change after change of climate in an almost endless succession, and even additional ice ages, presumably are still to be experienced, though, except small and fleeting changes to be noted below, when they shall begin, how intense they may be, or how long they shall last no one can form the slightest idea.

Numerous attempts, some of them invoking purely terrestrial and others extra-terrestrial or cosmical conditions, have been made to find a probable and at the same time an adequate physical basis for or cause of the known climatic changes of the distant past, and especially for those profound climatic changes that brought about the extensive glaciation that prevailed during the so-called ice ages; but nearly all the older suggestions have been definitely and finally abandoned, either because of inconsistency with known physical laws or abandoned because they are inadequate to meet the conditions imposed upon them by the results of geological investigations.

FACTS OF CLIMATIC CHANGES.

Among the more important facts with respect to climatic changes that appear to have been established, and which presumably, therefore, must be met by any theory that would account for such changes, or explain specifically the origin of ice ages, are the following:

(*a*) The climatic changes were several, probably many.

(*b*) They were simultaneous over the entire earth, and in the same sense; that is, colder everywhere at the same time (climatically speaking) or warmer everywhere.

(*c*) They were of unequal intensity.

(*d*) They probably were of irregular occurrence and of unequal duration.

(*e*) They, at least one or more, progressed with secondary variations of intensity, or with advances and retreats of the glacial edge.

(*f*) They have occurred from very early, probably from the

earliest, geological ages down to the present, and presumably will continue irregularly to recur for many ages yet to come.

PRINCIPAL ICE-AGE THEORIES.

It would be easy to catalogue perhaps a score of more or less rational hypotheses in regard to the origin of the ice ages, and doubtless even a larger number that are quite too absurd ever to have received serious consideration, and to point out in each case the known and the suspected elements of weakness. But this would only be a repetition of what, in part at least, has often been done before and therefore could serve no good purpose.

As already stated, only a few of these hypotheses still survive, nor do all of even these few really merit the following they have. Apparently those which still claim each a large number of adherents are, respectively:

(*a*) *Croll's Eccentricity Theory.** This is based on the assumption that when the earth's orbit is most eccentric, or when the earth's maximum solar distance differs most from its minimum solar distance, ice will accumulate to a great extent over that half of the globe which has its winter during aphelion.

For some time Croll's theory was very generally accepted, and it seems still to have many adherents, despite the destructive criticisms of Newcomb [1] and Culverwell.[2]

The chief objections to Croll's theory are:

1. That the assumption that midwinter and midsummer temperatures are directly proportional to the sun's heat at these times is not at all in accord with observed facts.

2. That each ice age would be limited to a fraction of the precessional period, 21,000 years, which, according to most geologists, is too short a time. In fact, it is already longer than this whole period, according to the best evidence, since the culmination of the last ice age.

3. That the successive ice ages would have occurred *alternately* in the northern and southern hemispheres, instead of, as generally believed to have been the case, in both hemispheres *simultaneously*.

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* *Phil. Mag.*, 28, p. 121, 1864, and elsewhere.

[1] *Amer. Jr. Sci.*, 11, p. 263, 1876; *Phil. Mag.*, 17, p. 142, 1884.

[2] *Phil. Mag.*, 38, p. 541, 1894.

(*b*) *The Carbon Dioxide Theory.* This theory, advocated by Tyndall,[3] Arrhenius,[4] Chamberlain,[5] and others, is based on the selective absorption of carbon dioxide for radiation of different wave-lengths, and on its assumed variation in amount.

It is true that carbon dioxide is more absorptive of terrestrial than of solar radiations, and that it therefore produces a green-house or blanketing effect, and it is also probably true that its amount in the atmosphere has varied through appreciable ranges as a result of volcanic additions on the one hand, and of oceanic absorption and chemical combination on the other. But it is not possible to say exactly how great an effect a given change in the amount of carbon dioxide in the atmosphere would have on the temperature of the earth. However, by bringing a number of known facts to bear on the subject it seems possible to reach approximate conclusions. Thus from the experiments of Schlaefer[6] we know that at atmospheric pressure a column of carbon dioxide 50 centimetres long is ample for maximum absorption, since one of this length absorbs quite as completely as does a column 200 centimetres long at the same density. Also from the experiments of Ångström[7] and from those of E. v. Bahr[8] we know that the absorption of radiation by carbon dioxide or other gas increases with increase of pressure, and, what is of great importance, that both qualitatively and quantitatively this increase of absorption is exactly the same whether the given higher pressure be obtained by compression or by the addition of an inert gas.

Now the amount of carbon dioxide in the atmosphere is equivalent to a column of the pure gas, at ordinary room temperature and atmospheric pressure, of, roughly, 250 centimetres in length. Hence, according to the experiments just described of Ångström and E. v. Bahr, the carbon dioxide now in the atmosphere must absorb radiation very approximately as would a column 475 centimetres long of the pure gas at its average barometric pressure of, say, 400 millimetres. But Schlaefer's experiments above referred to show that such a column would

[3] *Phil. Mag.*, 22, p. 277, 1861.
[4] *Phil. Mag.*, 41, p. 237, 1896.
[5] *Jr. Geol.*, 7, p. 545, 1899.
[6] *Ann. der Phys.*, vol. 16, p. 93, 1905.
[7] *Arkiv för Matematik, Astronomi och Fysik*, vol. 4, No. 30, 1908.
[8] *Ann. der Phys.*, vol. 29, p. 780, 1909.

be just as effective as one two or three times this length, and, on the other hand, no more effective than a column one-half or one-fourth as long.

Hence, finally, doubling or halving the amount of carbon dioxide now in the atmosphere, since this would make but little difference in the total pressure, would not appreciably affect the amount of radiation actually absorbed by it, whether of terrestrial or of solar origin.

Again, as already explained by Abbot and Fowle,[9] the water vapor always present in the atmosphere leaves, because of its high coefficients of absorption in substantially the same regions where carbon dioxide is effective, but little radiation for the latter to take up. Hence, for this reason, too, as well as for the one given above, either doubling or halving the present amount of carbon dioxide could alter but little the total amount of radiation actually absorbed by the atmosphere, and therefore, seemingly, could not appreciably change the average temperature of the earth, or be at all effective in the production of marked climatic changes.

Nevertheless, in spite of both the above objections, there appears to be at least one way by which a change, especially if a decrease, in the amount of carbon dioxide in the atmosphere might affect temperatures at the surface of the earth, so that we are not yet in position to say that no such change was ever an appreciable factor in the production of an ice age.

Further discussion of this particular point will be taken up later, after the introduction of certain observational evidence that seems to bear on the subject.

We will now return to the existing ice-age theories and consider briefly just two more before coming to the main body of the paper.

(*c*) *The Solar Variation Theory.* This is based on the assumption that the solar radiation has waxed and waned, either cyclically or irregularly, through considerable ranges and over long intervals of time.

This theory is seductively attractive,—it looks so simple, so sufficient, and so safe from attack. But if impossible to disprove, it is equally difficult to establish, and therefore it should conditionally be put aside, held in reserve, as it were, as a last

[9] Annals of the Astrophysical Observatory, Smithsonian Institution, vol. 2, p. 172, 1908.

resort, in favor of a more complete search for and examination of other possible causes, for, after all, the supposed solar changes, for which we can assign no probable cause or causes, may never have happened.

(*d*) *The Elevation Theory.* This theory assumes the simultaneous (geologically speaking) rise or fall of many, possibly all, land areas through a range that may have amounted to several thousand feet. It is argued that such movements would account for not only the phenomena of the ice ages, but also for, among other things, the many suboceanic canyons, such as that of the Hudson, the St. Lawrence, the Congo, and others.

This theory is mentioned here not because of the number of supporters it has at present, for obviously this number is not large, but because any such changes in elevation that it supposes, whether local or general, if they ever took place—and apparently great changes in elevation have occurred—must have affected the climates of the regions that so moved, and therefore must have been a factor—no one knows how great—in the production of at least regional, if not world-wide, climatic changes of the past.

These three theories, then, omitting *d*, which but few support, of the origin of the ice ages, namely: The eccentricity theory, the carbon dioxide theory, and the solar variation theory, are the only ones that at present appear to have many adherents, and even these few seem more likely to lose than to gain in number and strength of defenders. The first has failed utterly under searching criticism; the second has been sadly impaired; while the third, provokingly secure from all tests, is strong only as and to the extent that other theories are disproved or shown to be improbable.

The above introduction brings us to the essential purpose of this paper, to the discussion of a factor in the production of climatic changes including, possibly, even those great changes incident to the advance and retreat to maximum and minimum of glaciation. It may not have been the chief cause of our greatest climatic changes, or even a large contributing factor, but nevertheless a factor, possibly of large size, and therefore worthy of consideration.

The factor in question is

VOLCANIC DUST IN THE UPPER ATMOSPHERE.

After the outline of the following discussion had taken shape it was found, on looking up the appropriate literature, that the brothers P. and F. Sarasin [10] had suggested, a number of years ago, that the low temperature essential to the glaciation of ice ages was caused by the absorption of solar radiation by high volcanic dust-clouds.

But the idea that dust of this nature, when scattered through the atmosphere, may lower the temperature of the surface of the earth was already old, having been advanced at a much earlier date,—in fact, long before even the existence of ice ages had been suspected, much less attempts made to find their cause. Thus in May, 1784, Benjamin Franklin (and he may not have been the first) wrote as follows:

> During several of the summer months of the year 1783, when the effects of the sun's rays to heat the earth in these northern regions should have been the greatest, there existed a constant fog over all Europe, and great part of North America. This fog was of a permanent nature; it was dry, and the rays of the sun seemed to have little effect toward dissipating it, as they easily do a moist fog, arising from water. They were indeed rendered so faint in passing through it that, when collected in the focus of a burning-glass, they would scarce kindle brown paper. Of course, their summer effect in heating the earth was exceedingly diminished.
>
> Hence the surface was early frozen.
>
> Hence the first snows remained on it unmelted, and received continual additions.
>
> Hence perhaps the winter of 1783–4 was more severe than any that happened for many years.
>
> The cause of this universal fog is not yet ascertained. Whether it was adventitious to this earth, and merely a smoke proceeding from the consumption by fire of some of those great burning balls or globes which we happen to meet with in our course round the sun, and which are sometimes seen to kindle and be destroyed in passing our atmosphere, and whose smoke might be attracted and retained by our earth; or whether it was the vast quantity of smoke, long continuing to issue during the summer from Hecla, in Iceland, and that other volcano which arose out of the sea near that island, which smoke might be spread by various winds over the northern part of the world, is yet uncertain.
>
> It seems, however, worth the inquiry, whether other hard winters, recorded in history, were preceded by similar permanent and widely-extended summer fogs. Because, if found to be so, men might from such fogs con-

[10] *Verhandlungen der Naturforschenden Gesellschaft in Basel*, vol. 13, p. 603, 1901.

jecture the probability of a succeeding hard winter, and of the damage to be expected by the breaking up of frozen rivers in the spring; and take such measures as are possible and practicable to secure themselves and effects from the mischiefs that attend the last.[11]

The idea, then, that volcanic dust may be an important factor in the production of climatic changes is not new, though just how it can be so apparently has not been explained, nor has the idea been specificially supported by direct observations. This is not to be taken as a criticism of the above-mentioned pioneer paper by the brothers Sarasin, for indeed the arguments, now easy, were at that time impossible, because the observations upon which they largely are based had not then been made. Indeed the *absorption* of radiation by volcanic dust, by which they supposed the earth's temperature to be lowered, can now be shown to be, of itself alone, not only insufficient, but even productive, in all probability, of the opposite effect—of a warming instead of a cooling of the earth's surface.

To make this point clear: Consider a thin shell of dust about the earth and let I be the average intensity of the normal component of solar radiation on it. Further, let a be the dust's coefficient of absorption for solar radiation, independent, presumably, of intensity, and b its coefficient of absorption for terrestrial radiation. Obviously, in the case of equilibrium, all the energy absorbed by the dust is radiated away; half of it, very approximately, to the earth and half of it to space. Hence, starting with I as the solar radiation normally incident, per unit area and unit time, upon the dust layer, we have, if there is no reflection and no scattering,

aI = rate of absorption of solar radiation.

$I(1-a)$ = intensity of solar radiation reaching earth, or lower atmosphere.

$\frac{1}{2}aI$ = intensity of dust radiation, resulting from above absorption, reaching earth.

Summing these two radiations incident upon the earth, we have

$$I(1-a)+\frac{1}{2}aI=I\left(1-\frac{a}{2}\right).$$

Eventually, when equilibrium is established, the earth must lose the same amount of radiation that it gains, though, of

[11] See Sparks's "Life of Benjamin Franklin," vol. 6, 455–457 (cited in *Proceedings of the Amer. Phil. Soc.*, vol. 45, p. 127, 1906).

course, chiefly through a different spectral region, and therefore, after a time, assuming the earth to absorb all incident radiation,

$I\left(1-\frac{a}{2}\right)$ = the intensity of the outgoing as well as that of the incoming radiation.

Of this the dust absorbs, per unit area and unit time,

$$bI\left(1-\frac{a}{2}\right),$$

of which, in turn, one half is radiated to space and one half back to earth, there to be reabsorbed and again radiated. The intensity of the normal radiation now reaching the earth is

$$I\left(1-\frac{a}{2}\right)+\frac{b}{2}I\left(1-\frac{a}{2}\right),$$

of which the second term becomes, after a time, the increase in the intensity of the outgoing radiation. Hence, after further absorption and re-radiation by the dust layer, the next increment of radiation to the earth is

$$\left(\frac{b}{2}\right)^2 I\left(1-\frac{a}{2}\right),$$

and so on indefinitely.

In the end, then, when the ultimate equilibrium is attained, the intensity of the total normal radiation reaching the earth, I_e, is given by the equation,

$$I_e = I\left(1-\frac{a}{2}\right)\left\{1+\frac{b}{2}+\left(\frac{b}{2}\right)^2+\cdots+\left(\frac{b}{2}\right)^{\infty}\right\}$$

$$\text{or } I_e = I\left\{1+k\,(b-a)\right\} \quad \ldots\ldots\ldots \text{(A)}.$$

in which

$$k=\frac{1}{2}\left\{1+\frac{b}{2}+\left(\frac{b}{2}\right)^2+\cdots+\left(\frac{b}{2}\right)^{\infty}\right\}.$$

Now b is positive, and therefore k is also positive. Hence

$$I\left\{1+k\,(b-a)\right\}\gtreqless I,$$

according as $b \gtreqless a$.

That is to say, the total amount of radiation reaching the earth is increased, unchanged, or decreased by the surrounding dust layer according as the dust's coefficient of absorption of terrestrial radiation is greater than, equal to, or less than its coefficient of absorption of solar radiation.

Now in the case of many, if not all, rocky materials, such as make up the particles of volcanic dust, the coefficient of absorption is much greater for terrestrial radiation than for solar radiation,[12] or, in terms of the above symbols, in the case of volcanic dust b is greater than a. Hence, so far as mere absorption of radiation is concerned, the only action mentioned by the brothers Sarasin, a veil of volcanic dust, in all probability, would slightly *increase* and not decrease, as they supposed, the average temperature of the earth.

But, then, absorption is not the only effect of a dust veil on radiation; reflection and scattering both are important and must be fully considered.

These actions, however, reflection and scattering, depend fundamentally upon the ratio of the linear dimensions of the particles concerned to the wave-length of the incident radiation, and therefore, before undertaking to discuss them in this connection, it will be essential to determine the approximate size of the individual grains of floating volcanic dust, and also the average wave-lengths, weighted according to energy, of solar and of terrestrial radiation. It will be desirable, also, to consider whether or not, and if so how, dust of any kind can remain long suspended in the atmosphere. And this point will be examined first, since, obviously, the longer the dust can float the more important, climatically, it may have been in the past and in the future may again become.

Atmospheric Regions.—The atmosphere is divisible into the stratosphere and the troposphere; or the isothermal region and the convective region; or, in other words, the region, in middle latitudes, at and beyond about 11 kilometres above sea level where, being free from vertical convection, ordinary clouds never form and the turbulent, stormy region below this level which is frequently swept by clouds and washed by snow and rain. The

[12] Coblentz, Publications of Carnegie Institution of Washington, Nos. 65 and 97.

physical reason for or cause of the existence of the isothermal region is well known,[13] and is such that we feel quite sure that ever since the earth was warmed by solar radiation, as at present, rather than by internal heat, the temperature of its atmosphere beyond a certain level, whatever its composition, must have varied but little, as it now varies but little, with change of altitude, and therefore that this region must then have been free, as it now is free, from clouds and condensation. Obviously, then, in the past, as in the present, and as it must continue to be so long as the earth shall have an atmosphere, any volcanic or other dust, that by whatever process was gotten into and distributed through the isothermal region where there were no clouds or other condensation to wash it out, must have drifted about till gravity, overcoming the viscosity of the atmosphere, by slow degrees pulled it down to the region of clouds and storms. How long such a process must take depends, of course, upon a number of things, among which the size of the particles is vitally important. And this brings us to the next consideration.

Size of Volcanic Dust Particles.—For two or three years after the eruption of Krakatoa, in 1883, also after the eruptions of Mount Pelée and Santa Maria, in 1902, and again after the eruption of Katmai, in 1912, a sort of reddish-brown corona was often, under favorable conditions, observed around the sun. It was 10 degrees to 12 degrees wide, and had an angular radius, to the outer edge, of 22 degrees to 23 degrees. This phenomenon, known as Bishop's ring, clearly was a result of diffraction of sunlight by the particles of volcanic dust in the upper atmosphere, and therefore furnished a satisfactory means for determining the approximate size of the particles themselves. The subject has been rather fully discussed by Pernter,[14] who finds the diameter of the particles, assuming them spherical, to be approximately 185×10^{-6} cm., or 1.85 microns. The equation used has the form

$$r = \frac{m}{\pi} \frac{\lambda}{\sin \vartheta}$$

in which r is the radius of the dust particle, λ the wave-length of the diffracted light (here taken as 571×10^{-7} cm., or 0.571

[13] Humphreys, *Astrophys. Jr.*, 29, p. 14, 1909.
Gold, Proc. Roy. Soc., Series A, 82, p. 43, 1909.
[14] *Met. Zeit.*, 6, p. 401, 1889.

micron), ϑ the angular radius of the ring, and m a numerical term which for the outer edge of the ring, and successive minima, has the approximate values,

$$\frac{\pi}{2}(n + 0.22),$$

in which $n = 1,2,3,$—, respectively.

Now, since the width and angular dimensions of Bishop's ring, as seen at different times and under different circumstances, have varied but little, the above value, 1.85 microns, may provisionally be assumed to be the average diameter of those particles of volcanic dust that remain long suspended in the atmosphere.

Time of Fall.—The steady or terminal velocity of a sphere falling in a fluid, assuming no slip between fluid and sphere, is given by Stokes's [15] equation:

$$V = \frac{2}{9} g r^2 \frac{(\sigma - \rho)}{\mu},$$

in which V is the velocity of the fall, g the acceleration of gravity, r the radius of the sphere, σ the density of the sphere, ρ the density of the fluid, and μ its viscosity.

However, there always is slip, so that the actual velocity of fall is, according to Cunningham,[16]

$$V = \frac{2}{9} g r^2 \frac{(\sigma - \rho)}{\mu} \left(1 + A \frac{l}{r}\right),$$

in which l is the free path of the gas molecules, A a constant, and the other symbols as above explained.

Obviously l, other things being equal, is inversely proportional to the gas density, or pressure, if temperature is constant. Hence

$$V = \frac{2}{9} g r^2 \frac{(\sigma - \rho)}{\mu} \left(1 + \frac{B}{rp}\right) \text{- - - (1).}$$

in which B is a constant for any given temperature, p the gas pressure, or, if preferred, barometric height.

Now a series of valuable experiments by McKeehan [17] has shown that for 21° C., and when p is the pressure in terms of millimetres of mercury,

$$B = .0075 \pm 3.$$

[15] *Math. and Phys. Papers*, vol. 3, p. 59.
[16] Proc. Roy. Soc., 83 A, p. 357, 1910.
[17] *Phys. Rev.*, 33, p. 153, 1911.

The value of μ, for dry air, is also closely known from the careful work of Breiterbach,[18] Schultze,[19] and Fischer,[20] all of whom obtained substantially the same values. At 26° C., as computed by Millikan[21] from the results obtained by these observers,

$$\mu = 1863 \times 10^{-7}.$$

Therefore, remembering that μ varies as the square root of the absolute temperature, it is easy to compute, by the aid of equation (1), the velocity of fall of volcanic dust, assuming gravity to be the only driving force. There is, of course, radiation pressure, both toward and from the earth, as well as slight convective and other disturbances, but presumably gravitation exerts the controlling influence.

The following table of approximate velocities and times of fall for volcanic dust was computed by substituting in equation (1) the given numerical values, namely:

$g = 981 \frac{\text{cm.}}{\text{sec.}}$
$r = .000092$ cm.
$\sigma = 2.3$, approximate density of Krakatoa dust.
$\rho = 0$, being negligible relative to σ.
$\mu = 1760 \times 10^{-7}$, appropriate to $-55°$ C., roughly the temperature, in middle latitudes, of the isothermal region.
$B = .0056$, appropriate to $-55°$ C.
p = millimetres barometric pressure.

Velocity and time of fall.

Height in kilometres	Barometric pressure[22]	Centimetres per second	Seconds per centimetre
40	1.84	0.82173	1.2170
30	8.63	0.19419	5.2695
20	40.99	0.05992	16.690
15	89.66	0.04048	24.703
11*	168.00	0.03280	30.44
0	760.00	0.02522†	39.65†

* Isothermal level of middle latitudes.
† Temperature 21° C.

According to this table it appears that spherical grains of sand of the size assumed, 1.85 microns in diameter, would re-

[18] *Ann. der Phys.*, 5, p. 168, 1901.
[19] *Ann. der Phys.*, 5, p. 557, 1901.
[20] *Phys. Rev.*, 28, p. 104, 1909.
[21] *Phil. Mag.*, 19, p. 215, 1910.
[22] Humphreys, JOURNAL OF THE FRANKLIN INSTITUTE, 165, p. 215, 1913.

quire more than one year to fall from only that elevation already reached by balloons, 37.7 kilometres, down to the under surface of the isothermal region, at the height of 11 kilometres.

As a matter of fact, volcanic dust, at least much of it, consists of thin-shelled bubbles or fine fragments of bubbles, and therefore must settle much slower than solid spheres, the kind above assumed. Indeed, the finest dust from Krakatoa, which reached a great altitude, probably not less than 40 nor more than 80 kilometres, was from two and a half to three years in reaching the earth, or, presumably, as above explained, the upper cloud levels.

At any rate, volcanic dust is so fine, and the upper atmosphere above 11 kilometres so free from moisture and vertical convection, that once such dust is thrown into this region, as it obviously was by the explosions of Skaptar Jökull and Asamayama in 1783, Babuyan in 1831, Krakatoa in 1883, Santa Maria and Pelée in 1902, Katmai in 1912, and many others, it must require, as a rule, because of its slow descent, from one to three years to get back to the earth. And this clearly has always been the case since the earth first assumed substantially its present condition, or had a cool crust and a gaseous envelope.

Obviously, then, we have only to determine the present action of such dust on incoming solar and outgoing terrestrial radiation in order to reach a logical deduction as to what its effect on climate must have been if, through extensive volcanic activity, it ever for a long or even considerable term of years more or less continuously filled the upper atmosphere, as conceivably may have happened. And the same conclusion in regard to the possible effect of dust on the climates of the past clearly applies with equal force to the climates of the future.

Action of Dust on Solar Radiation.—Since solar radiation at the point of maximum intensity [23] has a wave-length less than 5×10^{-5} cm., or half a micron, and since fully three-fourths of the total solar energy belongs to spectral regions whose wave-lengths are less than 10^{-4} cm., or one micron, it follows that the cubes of solar wave-lengths must, on the whole, be regarded as small in comparison with the volume of a volcanic dust particle—the diameter of which, as we have seen, is nearly 2 microns.

[23] Abbot and Fowle, Annals Astrophys. Obsy., Smithsonian Inst., vol. 2, p. 104, 1908.

Hence, in discussing the action of volcanic dust on incoming solar radiation, we can, with more or less justification, assume the particles to be opaque through reflection or otherwise, and therefore use Rayleigh's [24] arguments as applied to a similar case.

Let r be the radius of the particle, n the number of particles per cubic centimetre, and a the projected joint area of these particles. Then, for random and sparsely-scattered particles,

$$a = n\pi r^2$$

Hence, on dividing a plane parallel to the wave front into Fresnel zones, we see that for each centimetre traversed the amplitude of the radiation is reduced in the ratio of 1 to $1 - n\pi r^2$, therefore, if A is the initial amplitude, and A_x the amplitude after passing through x centimetres of the uniformly dusty region, we have, assuming $n\pi r^2$ to be only a small fraction of a square centimetre,

$$A_x = A(1-n\pi r^2)^x = Ae^{-n\pi r^2 x}$$

Further, if I is the initial and I_x the final intensity, then

$$I_x = Ie^{-2n\pi r^2 x}$$

Hence, in the case of volcanic dust, where, as already explained, $r = 92 \times 10^{-6}$ centimetres,

$$A_x = Ae^{-n\pi x\,(92)^2\,10^{-12}}$$

and

$$I_x = Ie^{-2n\pi x\,(92)^2 10^{-12}}$$

Presumably the particles of dust are not absolutely opaque and therefore I_x probably is a little larger than the value here given, though even so this value is at least a first approximation.

Action of Dust on Terrestrial Radiation.—Terrestrial radiation, at the point of maximum intensity, has a wave-length of, roughly, 12×10^{-4} centimetres, and therefore the wave-lengths of nearly all outgoing radiation are large in comparison with the diameters of those volcanic dust particles that remain long suspended in the atmosphere. Hence, while such particles largely *reflect* solar radiation, as is obvious from the whiteness

[24] *Phil. Mag.*, 47, p. 375, 1899.

of the sky when filled by them, they can only *scatter* radiation from the earth, according to the laws first formulated by Rayleigh,[25] whose papers must be consulted by those who would fully understand the equations which here will be assumed and not derived.

Let E be the intensity of terrestrial radiation as it enters the dusty shell, or as it enters the isothermal region, and E_y its intensity after it has penetrated this region, supposed uniformly dusty, a distance y centimetres; then, remembering that the dust particles are supposed to be spherical, we have

$$E_y = Ee^{-hy}$$

where

$$h = 24\pi^3 n \frac{(K'-K)^2}{(K'+2K)^2} \frac{T^2}{\lambda^4},$$

in which n is the number of particles per cubic centimetre, K the dielectric constant of the medium, K' the dielectric constant of the material of the particles, T the volume of a single particle, and λ the wave-length of the radiation concerned.

But $K = 1$, and, since the dust seems generally to be a kind of a glass, it may not be far wrong to assume that $K' = 7$. Hence, with these values,

$$h = 11\pi^3 n \frac{T^2}{\lambda^4}, \text{ nearly.}$$

Relative Action of Dust on Solar and Terrestrial Radiation.—To determine whether such a dust layer as the one under discussion will increase or decrease earth temperatures it is necessary to compare its action on short wave-length solar radiation with its action on long wave-length radiation from the earth.

In the case of solar radiation, as explained,

$$I_x = Ie^{-2n\pi x(92)^2 10^{-12}}$$

Clearly, then, the intensity of the solar radiation is reduced in the ratio of 1 to e, or

$$I_x : I = 1 : e$$

when $$x = \frac{10^{12}}{2n\pi(92)^2} \text{ centimetres} = \frac{188}{n} \text{ kilometres, approximately.}$$

[25] *Loc. cit.*

On the other hand, in the case of terrestrial radiation, where

$$E_y = Ee^{-11\pi^3 n} \frac{T^2}{\lambda^4} y,$$

the intensity is reduced in the ratio of $1 : e$, or

$$E_y : E = 1 : e,$$

when $y = \frac{\lambda^4}{11\pi^3 n T^2}$ centimetres,

in which $T = \frac{4}{3}\pi (92)^3 10^{-18}$

and $\lambda = 12 \times 10^{-4}$, the region of maximum intensity.

Hence $y = \frac{5700}{n}$ kilometres, approximately.

Therefore, finally,

$$y : x = 30 : 1, \text{ roughly,}$$

or the shell of volcanic dust, the particles all being the size given, is some thirty-fold more effective in shutting solar radiation out than it is in keeping terrestrial radiation in. In other words, the veil of dust produces an inverse green-house effect, and hence, if the dust veil were indefinitely maintained, the ultimate equilibrium temperature of the earth would be lower than it is when no such veil exists.

The ratio 30 to 1 in favor of terrestrial radiation in its ability to penetrate the dusty atmosphere may at first seem quite too large, but it should be remembered that the dust particles in question are to terrestrial radiation in general as air molecules are to solar radiation, in the sense that in both cases but little more than mere scattering takes place. Now it is obvious that the dust particles are many-fold more effective in intercepting solar radiation, which they appear to do chiefly by reflection, than are an equal number of air molecules which simply scatter it; and hence it may well be that the above theoretically-determined ratio, 30 to 1, is no larger than the ratio that actually exists, or, at any rate, that it is of the correct order.

It must be distinctly understood that certain of the assumptions upon which the foregoing is based, uniformity of size, complete opacity and sphericity of the dust particles, for instance, are only approximately correct, but they are the best

that at present can be made, and doubtless give at least the order of magnitude of the effects, which indeed, for the present purpose, is quite sufficient.

It may be well, in this connection, to call attention to the fact that excessively fine dust particles, or particles whose diameters are half, or less, the wave-length of solar radiation (region of maximum intensity), and which therefore remain longest in suspension, shut out solar radiation many-fold more effectively than they hold back terrestrial radiation. This is because both radiations, solar and terrestrial, are simply scattered by such small particles, and scattered according to the inverse fourth power of the wave-length.

Now the ratio of solar wave-length to terrestrial wave-length (region of maximum intensity in both cases) is roughly 1 to 25, and therefore the ratio of their fourth powers as 1 to 39×10^4, about. Hence, in the case of the very finest and therefore most persistent dust, the interception of outgoing radiation is wholly negligible in comparison with the interception of incoming solar radiation.

Let us next see what observational evidence, pyrheliometric or otherwise, we have bearing on the effect of volcanic dust on radiation.

Pyrheliometric Records.—Direct measurement of solar radiation by means of the pyrheliometer shows marked fluctuations from year to year in the intensity of this radiation as received at the surface of the earth. This subject has been carefully studied by Dr. H. H. Kimball,[26] of the United States Weather Bureau, and Fig. 1, kindly prepared by him for use in this article, graphically represents the course of pyrheliometric readings from the beginning of 1883 till and including April, 1913. The yearly values are given in terms of the average value for the entire period, and, therefore, percentages of this average do not represent the full effect of the disturbing causes, of which volcanic dust certainly is the chief.

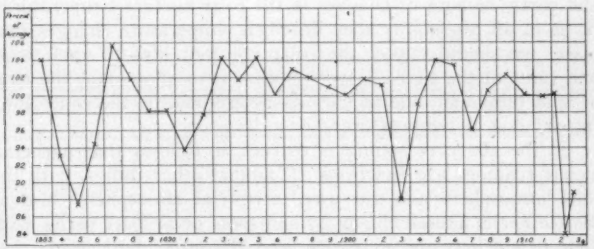
The marked decrease in the pyrheliometric readings for 1884, 1885, and 1886 doubtless were largely, if not almost wholly, due to the eruption of Krakatoa in the summer of 1883; the decreased values of 1888 to 1892 inclusive occurred during

[26] Bull. Mt. Weather Obsy., 3, p. 69, 1910.

a period of exceptional volcanic activity, but were most probably due essentially to the violent eruptions of Bandaisan (1888), Bogoslof (1890), and Awoe, on Great Sangir (1892); the low values of 1903 to the eruptions of Santa Maria, Pelée, and Colima; and the present low values, 1912–1913, to the recent (1912) explosion of Katmai.

There is then abundant pyrheliometric evidence that volcanic dust in the upper atmosphere actually does produce that decrease in direct solar radiation that theory indicates it should, and,

FIG. 1.



Annual average pyrheliometric values.

as the theory is well founded and the observations carefully taken, this mutual confirmation may be regarded as conclusive both of the existence of volcanic dust in the upper atmosphere (isothermal region) and of its efficiency in intercepting direct radiation from the sun.

It should be remembered, however, in this connection, that the intensity of the solar radiation at the surface of the earth depends upon not only the dustiness of the earth's atmosphere, but also upon the dustiness, and, of course, the temperature, of the solar atmosphere.

Obviously, dust in the sun's envelope must more or less shut in solar radiation just as, and in the same manner that, dust in the earth's envelope shuts it out. Hence it follows that when this dust is greatest, other things being equal, the output of solar energy will be least, and that when the dust is least, other things being equal, the output of energy will be greatest.

Not only may the intensity of the emitted radiation vary because of changes in the transparency of the solar atmosphere, but also because of any variations in the temperature of the effective solar surface, which, it would seem, might well be hottest when most agitated, or at the times of spot maxima, and coolest when most quiescent, or at the times of spot minima.

Now the dustiness of the solar atmosphere, manifesting itself as a corona, certainly does vary through a considerable range from a maximum when the sun-spots are most numerous to a minimum when they are fewest, and therefore, partly because of changes in the transparency of the solar envelope, and partly because of changes in the solar surface temperatures, if, as in all probability they do, such temperature changes take place, we should expect the solar constant also to vary from one value at the time of spot maximum to another at the time of spot minimum, and to vary as determined by the controlling factor, dust or temperature.

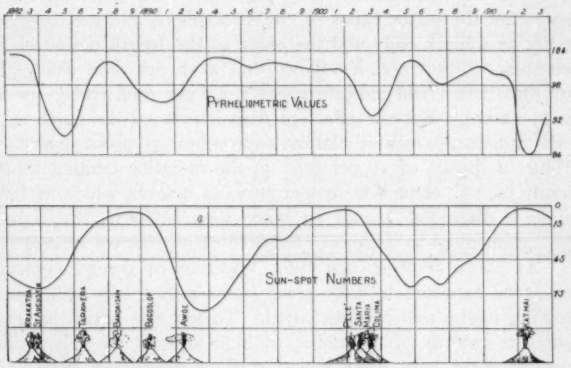
If the above reasoning is correct, it follows that pyrheliometric readings are functions of, among other things, both the solar atmosphere and our own terrestrial atmosphere; and as the former is altered chiefly by sun-spots or at least varies with their production and existence, and the latter by volcanic explosions, a means is at hand for comparing the relative importance of the two radiation screens.

Fig. 2 shows one such comparison. The upper curve gives smoothed annual average pyrheliometric readings (not solar constants, though closely proportional to them) and the lower curve sun-spot numbers. It will be noticed that in their most pronounced features the two curves have but little in common, and that the great drops in the pyrheliometric values occur simultaneously with violent volcanic explosions, as already explained, and not at the times of sun-spot changes. Hence it appears that the dust in our own atmosphere, and not the condition of the sun, is the controlling factor in determining the magnitudes and times of occurrence of great and abrupt changes of insolation intensity at the surface of the earth.

This is what the curves positively show, but it is not all they indicate. From 1894 to 1901 there were no volcanic explosions, so far as known, of importance, and therefore during this time the upper atmosphere must have been more or less uniformly

free from dust. But there seems to have been, during this interval, a slow decrease in the pyrheliometric values, and presumably, therefore, in the solar constant; also during exactly this same interval the number of sun-spots slowly decreased. Again, from 1905 to 1911 the same general trends of the curves, a decrease in the pyrheliometric values simultaneously with a decrease in the number of sun-spots, repeat themselves. Hence the indication—it is impossible yet to call it a certainty—seems to be that the solar constant, and hence, presumably, the effective surface temperature of the sun, is a little, though not much, greater at the times of spot maxima than at the times of spot minima.

FIG. 2.



Relation of pyrheliometric values to sun-spot numbers and volcanic eruptions.

Surface Temperatures.—If a veil of dust actually should intercept as much as one-fifth of the direct solar radiation, as Fig. 1 indicates that at times it does, it would seem that in those years the surface temperatures of the atmosphere should be somewhat below the normal. Of course, the great supply of heat in the ocean would produce a lag in this effect, and, besides, there must be both an increase of sky light by scattering and some interception of earth radiation by the dust which, since it is at great altitudes, receives the full, or nearly the full, planetary radiation of the earth. This increase of sky radiation,

together with the return terrestrial radiation, obviously compensates in some measure for the loss of direct insolation.

However, measurements made by Abbot[27] at Bassour, Algeria, during the summer of 1912, show that at this time and place the direct radiation and the sky radiation, which obviously included both the scattered solar radiation and some return terrestrial radiation, were together less by about 10 per cent. than their normal combined values; and there is no reason to think that in this respect Bassour was at all different from other places, probably the whole earth, covered by the veil of dust. Clearly, then, if this decrease in the radiation received should continue indefinitely, the ultimate radiation of the earth would also decrease to the same extent, or 10 per cent. Now, since the earth, or rather the water vapor of the atmosphere, radiates substantially as a black body and therefore as the fourth power of its absolute temperature, it follows that a 10 per cent. change in its radiation would indicate about a 2.5 per cent. change in its temperature. But the effective temperature of the earth as a full radiator, which it closely approaches, is about 256° C.[28] Hence a change of 10 per cent. in the radiation emitted would imply 6.4° C. change in temperature, an amount which, if long enough continued, would be more than sufficient to produce glaciation equal to the most extensive of any known ice age.

As above implied, not much lowering of the temperature could be expected to take place immediately, but, still, some cooling might well be anticipated. To test this point the temperature records of a number of high altitude (together with two or three very dry) inland stations have been examined. High altitudes were chosen because it might be expected that the temperature contrast between normal and dusty years would be greatest where the amount of atmosphere traversed below the dust layer is least; and the condition that the stations should also be inland was imposed because these are freer, presumably, than many coast stations, from fortuitous season changes. Thus, stations in the eastern portion of the United States are rejected because of the great differences in the winters, for example, of

[27] Smithsonian Miscellaneous Collections, vol. 60, No. 29, 1913.

[28] Abbot and Fowle, Annals Astrophys. Obsy., Smithsonian Institution, vol. 2, p. 175, 1908.

this section depending upon conditions wholly independent, so far as known, of variations in the intensity of direct radiation.

The number of stations was still further limited by the available recent data. Hence the records finally selected, and kindly put in shape by the Climatological Division of the United States Weather Bureau, Mr. P. C. Day in charge, for use in this article, were obtained at the following places:

TABLE I.

STATIONS WHOSE DATA WERE USED.

Name.	Latitude.	Longitude.	Elevation in feet.
America.			
Baker	44° 46′ N.	117° 50′ W.	3,466
Bismarck	46° 47′ N.	100° 38′ W.	1,674
Cheyenne	41° 08′ N.	104° 48′ W.	6,088
Denver	39° 45′ N.	105° 00′ W.	5,291
Dodge City	37° 45′ N.	100° 00′ W.	2,509
El Paso	31° 47′ N.	106° 30′ W.	3,762
Helena	46° 34′ N.	112° 04′ W.	4,110
Huron	44° 21′ N.	98° 14′ W.	1,306
North Platte	41° 08′ N.	100° 45′ W.	2,821
Red Bluff	40° 10′ N.	122° 15′ W.	332
Sacramento	38° 35′ N.	121° 30′ W.	69
Salt Lake City	40° 46′ N.	111° 54′ W.	4,360
San Antonio	29° 27′ N.	98° 28′ W.	701
Santa Fe	35° 41′ N.	105° 57′ W.	7,013
Spokane	47° 40′ N.	117° 25′ W.	1,929
Winnemucca	40° 58′ N.	117° 43′ W.	4,344
Yuma	32° 45′ N.	114° 36′ W.	141
Europe.			
Mont Ventoux	44° 10′ N.	5° 16′ E.	6,234
Obir	46° 30′ N.	14° 29′ E.	6,716
Pic du Midi	42° 56′ N.	0° 8′ E.	9,380
Puy de Dôme	45° 46′ N.	2° 57′ E.	4,813
Sântis	47° 15′ N.	9° 20′ E.	8,202
Schneekoppe	50° 44′ N.	15° 44′ E.	5,359
Sonnblick	47° 3′ N.	12° 57′ E.	10,190
India.			
Simla	31° 6′ N.	77° 12′ E.	7,232

In Table II the first column gives the year in question. The second column gives the average departure in degrees F., for the seventeen American stations, of the annual average maximum, as determined from the monthly average maxima, from the normal annual maximum, or average of a great many annual

average maxima. The third column gives smoothed values, determined from the actual values in the second column as follows:

$$S = \frac{a + 2b + c}{4},$$

in which S is the smoothed value, b the actual value pertaining to the particular year for which S is being computed, a and c the actual values for the next previous and the next succeeding years respectively. The fourth and fifth columns give respectively the actual and the smoothed average departures of the annual average minima, while the sixth and seventh columns give the corresponding average departures of the annual average means.

TABLE II.

AVERAGE TEMPERATURE DEPARTURES FROM TEMPERATURE NORMALS.

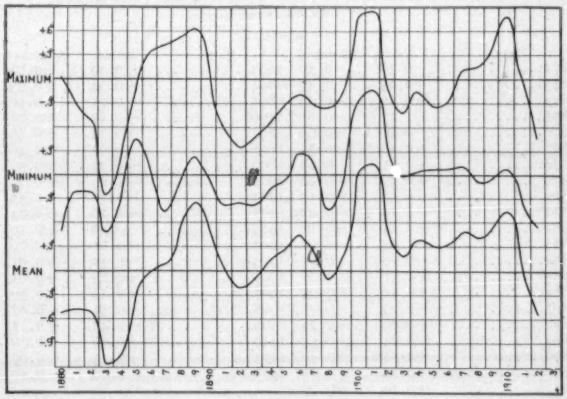
America.

Year.	Maxima.		Minima.		Means.	
	Actual.	Smoothed.	Actual.	Smoothed.	Actual.	Smoothed.
1880	−1.3	+0.03	−1.8	−0.68	−1.7	−0.50
1881	+0.2	−0.30	+0.6	−0.20	+0.1	−0.48
1882	−0.3	−0.50	−0.2	−0.20	−0.4	−0.50
1883	−1.6	−1.33	−1.0	−0.70	−1.3	−1.15
1884	−1.8	−1.20	−0.6	−0.28	−1.6	−1.05
1885	+0.4	−0.18	+1.1	+0.43	+0.3	−0.30
1886	+0.3	+0.35	+0.1	+0.10	−0.2	−0.03
1887	+0.4	+0.38	−0.9	−0.45	0.0	+0.07
1888	+0.4	+0.53	−0.1	−0.13	+0.5	+0.53
1889	+0.9	+0.63	+0.6	+0.23	+1.1	+0.85
1890	+0.3	+0.15	−0.2	−0.05	+0.7	+0.58
1891	−0.9	−0.58	−0.4	−0.38	−0.2	+0.05
1892	−0.8	−0.85	−0.1	−0.33	−0.1	−0.20
1893	−0.9	−0.73	−0.7	−0.38	−0.4	−0.08
1894	−0.3	−0.55	+0.4	−0.18	+0.6	+0.13
1895	−0.7	−0.35	−0.8	−0.08	−0.3	+0.25
1896	+0.3	−0.18	+0.9	+0.28	+1.0	+0.45
1897	−0.6	−0.30	+0.1	+0.13	+0.1	+0.28
1898	−0.3	−0.65	−0.6	−0.45	−0.1	−0.13
1899	−0.8	−0.13	−0.7	−0.10	−0.4	+0.25
1900	+1.4	+0.78	+1.6	+0.90	+1.9	+1.23
1901	+1.1	+0.83	+1.1	+1.08	+1.5	+1.35
1902	−0.3	−0.13	+0.5	+0.38	+0.5	+0.53
1903	−1.0	−0.43	−0.6	−0.05	−0.4	+0.18
1904	+0.6	−0.15	+0.5	+0.05	+1.0	+0.38
1905	−0.8	−0.30	−0.2	+0.08	−0.1	+0.33
1906	−0.2	−0.30	+0.2	+0.08	+0.5	+0.33
1907	0.0	+0.10	+0.1	+0.10	+0.4	+0.50
1908	+0.6	+0.15	0.0	−0.08	+0.7	+0.43
1909	−0.6	+0.38	−0.4	−0.05	−0.1	+0.55
1910	+2.1	+0.80	+0.6	+0.08	+1.7	+0.75
1911	−0.4	+0.03	−0.5	−0.35	−0.3	+0.05
1912	−1.2	−0.70	−1.0	−0.63	−0.9	−0.53

Fig. 3 shows the graphical equivalents of the smoothed portions of Table II.

It will be noticed that the three curves of Fig. 3, marked max., min., and mean respectively, are, in general, quite similar to each other. Hence, because of this mutual check and general agreement, we feel reasonably certain that any one set of tem-

FIG. 3.



Smoothed averages of the annual average temperature departures of 17 American stations.

perature data, the means for instance, furnishes a fairly safe guide to the actual temperature and climatic fluctuations from year to year or period to period.

Table III gives the weighted actual average departures and the smoothed departures in degrees F. of the annual mean temperatures of the selected seventeen American, seven European, and one Indian stations listed in Table I.

The average departures were calculated in accordance with the more or less correctly coefficiented equation,

$$D = \frac{4A + 2E + I}{7},$$

in which D is the weighted departure, A the smoothed average American, E the smoothed average European, and I the smoothed

Indian departure of the mean annual temperature from the normal annual temperature.

Table III, extended, as well as the scanty early data, mainly from the given stations, will permit, back to 1872, is graphically represented by the continuous light curve at the bottom of Fig. 4. In 1880 and again in 1901 the curve probably does not very

TABLE III.

WEIGHTED DEPARTURES OF MEAN TEMPERATURES FROM NORMAL TEMPERATURES.

World.

Date.	Actual.	Smoothed.	Date.	Actual.	Smoothed.
1872	−0.78	−0.30	1893	−0.34	−0.06
1873	−0.65	−0.47	1894	+0.34	+0.03
1874	+0.20	−0.34	1895	−0.21	+0.10
1875	−1.12	−0.61	1896	+0.49	+0.28
1876	−0.40	−0.60	1897	+0.34	+0.45
1877	−0.48	−0.32	1898	+0.61	+0.46
1878	+0.07	0.00	1899	+0.27	+0.59
1879	+0.33	+0.04	1900	+1.19	+0.76
1880	−0.50	−0.13	1901	+0.40	+0.55
1881	+0.14	−0.02	1902	+0.20	+0.13
1882	+0.14	−0.16	1903	−0.30	+0.10
1883	−1.04	−0.68	1904	+0.81	+0.20
1884	−0.79	−0.61	1905	−0.51	+0.01
1885	+0.17	−0.09	1906	+0.23	+0.05
1886	+0.11	+0.03	1907	+0.23	+0.30
1887	−0.29	−0.05	1908	+0.51	+0.21
1888	+0.26	+0.24	1909	−0.43	+0.11
1889	+0.74	+0.57	1910	+0.69	+0.30
1890	+0.54	+0.40	1911	+0.23	+0.09
1891	−0.21	+0.06	1912	−0.80	−0.40
1892	+0.10	−0.09			

closely represent world-wide temperature departures, being, presumably, at both places quite too low, owing, in each case, to an abnormally cold single month in America.

From 1907 to 1911 the dotted curve gives the average temperature departures for the American stations only, and presumably represents world temperature departures much more closely than does the continuous light line for the same time. This is because of two or three exceptionally cold summer months in Europe.

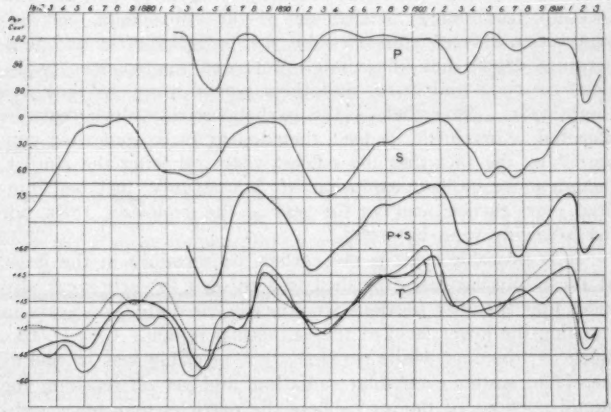
The dotted curve from 1872 to 1900 gives the smoothed averages of the annual temperature departures from the normal temperatures of the following stations as computed from the actual departures given by Nordmann:[29] Sierra Leone, Recife

[29] *Revue Général des Sciences*, August, 1903, pp. 803–808.
Annual Report, Smithsonian Institution, 1903, pp. 139–149.

(or Pernambuco), Port au Prince, Trinité, Jamaica, Habana, Manila, Hong Kong, Zikawei, Batavia, Bombay, Island of Rodriguez, Island of Mauritius.

All these, or practically all, are low-level stations, and most of them either tropical or semi-tropical, and therefore should show in general a smaller temperature range than the high altitude stations whose temperature departures are given by the continuous fine line curve. Hence, all things considered, the average temperature departures as calculated from the two sets

FIG. 4.



Smoothed pyrheliometric, sun-spot, and temperature curves.

of stations agree remarkably well, so that one can say with a fair degree of confidence that the heavy curve *T* approximately represents the average of the departures of the mean annual temperatures from the normal annual temperatures of the entire earth, or that *T* is the curve of world temperatures.

Relation of World Temperatures to Pyrheliometric Values.—Curve *P*, also of Fig. 4, gives the smoothed course of the annual average pyrheliometric readings, as computed from the actual values given in Fig. 1. The insolation intensity data, covering the whole of the depression that has its minimum in 1885, were

obtained at a single place, Montpellier, France, by a single observer, L. J. Eon,[80] who confined himself to noon observations with a Crova actinometer. It may be, therefore, that merely local and temporary disturbances produced a local insolation curve that was not quite parallel to the curve for the entire world. At any rate, the drop in the solar radiation values obviously was due to dust put into the atmosphere by the explosion of Krakatoa in August, 1883, and it would seem that the effects of this dust both on the surface temperatures and on pyrheliometric values must have been greater during the latter part of 1883 and in 1884 than they were in 1885, when much of the dust certainly had already settled out of the atmosphere, and this supposition is well supported by the pyrheliometric and temperature drops that immediately followed the volcanic explosions of 1903 and 1912, and their partial recovery within a single year. Nevertheless, the pyrheliometric values must be accepted as obtained. Indeed, they appear to be somewhat supported by the fact that the coldest year following the similar. though more violent, explosion of Asamayama, just one hundred years earlier, was not the year of the explosion, 1783, nor the following year, but 1785.

It is probable that in the earlier, as certainly in the later, of these unusual cases the dust was thrown to such great altitudes that the finer portions were nearly, or quite, two years in reaching the lower level of the isothermal region. Clearly, too, much of this dust, while perfectly dry, probably was so fine as merely to scatter even solar radiation, and yet on reaching the humid portions of the atmosphere the particles may have gathered sufficient moisture to assume reflecting size, and therefore seriously to interfere with insolation. This is merely suggested, but in no wise insisted upon, as a possible explanation of the unusual pyrheliometric lag after the explosion of Krakatoa.

It is obvious, from a mere glance, that the pyrheliometric and the temperature curves, or curves P and T, have much in common. This is especially marked by the large and practically simultaneous drops in the two curves in 1912, following the eruption of Katmai. But while a relation between these curves thus appears certain, the agreement is so far from perfect as

[80] Bulletin météorologique du Département de l'Herault, 1900.

to force the conclusion that pyrheliometric values constitute only one factor in the determination of average world temperatures.

Sun-spots and Temperature.—It has been known for a long time that the curve of sun-spot numbers, curve S, Fig. 4, and the curve of earth temperatures, curve T, follow or parallel each other in a general way, in the sense that the fewer the spots the higher the temperature, with, however, puzzling discrepancies here and there. Both these facts, the general agreement between the phenomena in question and also their specific discrepancies, are well shown by the curves S and T of Fig. 4, and, while the discrepancies are marked, it is obvious that, on the whole, the agreement is quite too close to leave any doubt of the reality of some sort of connection between sun-spots and atmospheric temperatures. Just how or by what process this relation exists will be discussed below.

Combined Effect of Insolation Intensity and Sun-spot Influence on Atmospheric Temperatures.—Since it is obvious that the insolation intensity and the number of sun-spots each exerts an influence on the temperature of the earth, it is clear that some sort of a combination of the two curves P and S should more closely parallel the temperature curve T than does either alone. It is probable that the sun-spot effect is not directly proportional to the actual number of spots, but, however this may be, the direct combination of the curves P and S gives the resultant $P + S$, which, as a glance at the figure shows, actually parallels the curve of temperatures T with remarkable fidelity. Exactly this same combination, from 1880 to 1909, has just been made by Abbot and Fowle,[31] whose lead in this important particular is here being followed, and the resultant curve found to run closely parallel to the curve of "smoothed annual mean departures" of the maximum temperatures of fifteen stations in the United States.

Probably the most striking point of agreement, as shown by Fig. 4, between the combination curve and the temperature curve, occurs in 1912, where, in spite of the fact that the sun-spots were at a minimum, the temperature curve dropped greatly and abruptly; obviously because of the simultaneous and cor-

[31] Smithsonian Miscellaneous Collections, vol. 60, No. 29, 1913.

responding decrease in the intensity of solar radiation produced by the extensive (presumably world wide) veil of Katmai's dust.

Temperature Variations Since 1750 as Influenced by Sun-spots and Volcanic Eruptions.—Sun-spot numbers[32] month by month are fairly well known since July, 1749, and so, too, are the annual temperature variations[33] from about the same time, and therefore the data are at hand for comparing these two phenomena over a continuous period of a little more than 163 years, or from at least the beginning of the year 1750 to the present date. Fig. 5 makes this comparison easy. The bottom curve gives the smoothed annual temperature departures, as computed from Köppen's actual annual departures, using all stations, while the top curve follows Wolfer's annual average sun-spot numbers. Of course, the earlier observations, both of sun-spots and of temperatures, were few in number and more or less unsatisfactory in comparison with those obtained during the past thirty, or even forty, years. Nevertheless, it is clear from Fig. 5 that at least since 1750, the date of our earliest records, and presumably, therefore, since an indefinitely distant time in the past, the two phenomena, atmospheric temperature and sun-spot numbers, have in general varied together, with, however, marked discrepancies from time to time. These we shall now consider, and show that they occurred, in every important case, simultaneously with violent volcanic eruptions.

Volcanic Disturbances of Atmospheric Temperature Since 1750.—It must be distinctly remembered that the earlier temperature records, because of their limited number, if for no other reason, can give us only the general trend of world temperatures. Again, the record back to 1750 of even violent volcanic eruptions is necessarily incomplete; and, besides, not all great eruptions decrease the world's temperature—only those that drive a lot of dust into the isothermal region. Extensive and long-continued sky phenomena, therefore, of the type that followed the eruption of Krakatoa, furnish the best evidence of volcanic violence in the sense here used. Finally, there can be no particular test save where the temperature is low in com-

[32] Wolfer, Astronomische Mitteilungen, 93, 1902, and later numbers.

[33] Köppen, *Zeit. Österreich. Gesell. für Meterologie*, vol. 8, 241 and 257, 1873.

parison with that which the number of sun-spots would lead us to expect. Obviously, then, no matter how close the actual relation between the phenomena may be, the errors and the incompleteness of the recorded data would prevent the discovery of more than a general relation.

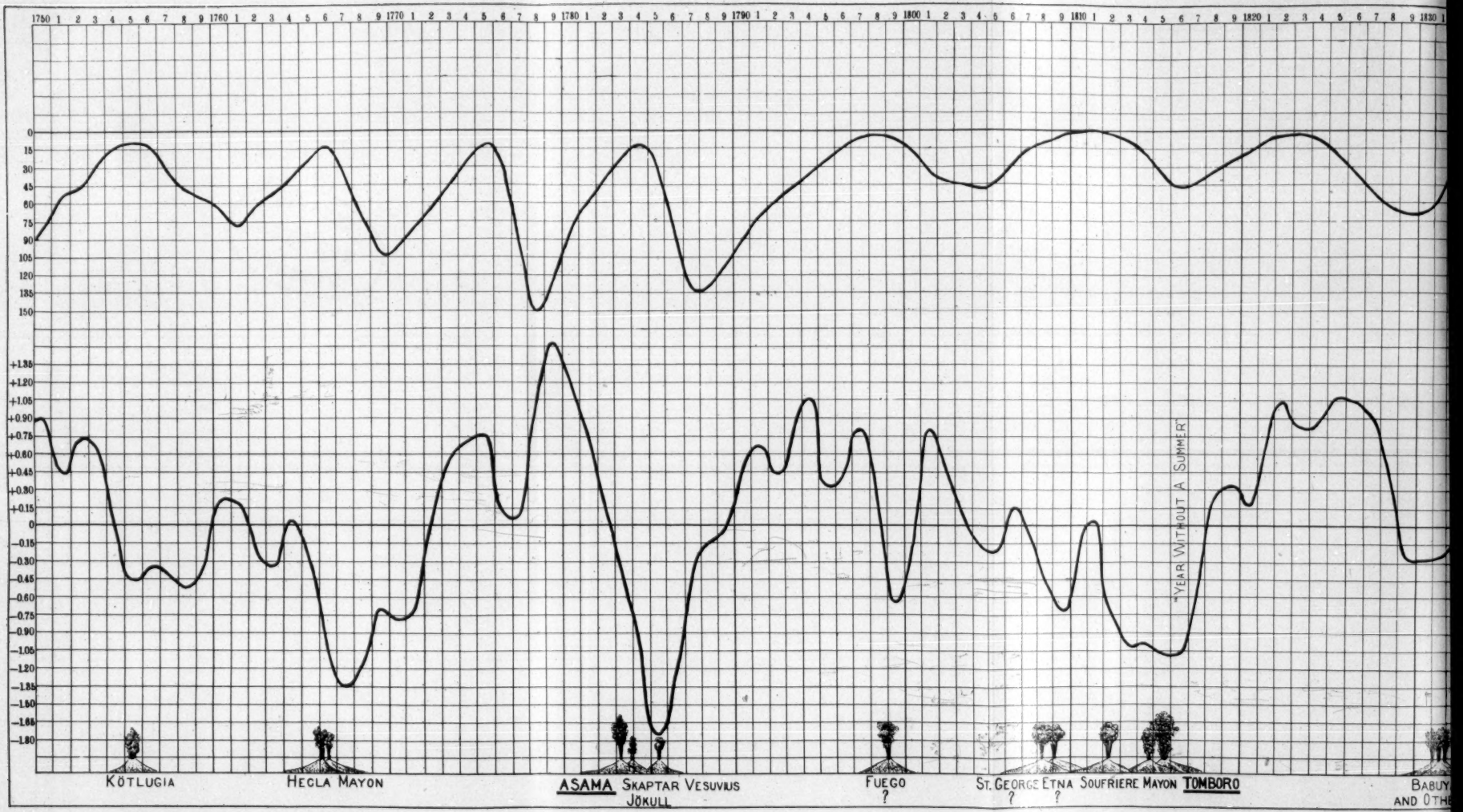
Of course, it will naturally occur to one to ask about special cases, such as the cold years of 1783–4–5, and, in particular, 1816, the famous "year without a summer," "poverty year," or "eighteen hundred and froze to death." The first of these, 1783–5, followed, as already explained, the great explosion of Asama in 1783, while the second, the "year without a summer," that was cold the world over, followed the eruption of Tomboro, which was so violent that 56,000 people were killed [34] and "for three days there was darkness at a distance of 300 miles." [35]

There is a detail in the temperature curve for the years 1886–7 that needs special attention. The temporary depression where, seemingly, the temperature should be steadily rising, obviously was due to the great eruption of Tarawera, in New Zealand. This volcano is a little more than 38° south of the equator, and therefore furnishes a good example of an eruption on one side of the equator affecting the temperature far to the other side. Doubtless, however, when the dust gets but a little way into the isothermal region the effect is greatest on the volcano's side of the equator.

But if the temperature was decreased by Tarawera, why, one might ask, was not the pyrheliometric curve similarly affected? It was, for several months after the eruption, as the individual monthly values show, but the annual means, plotted in the figure, have the effect of making the pyrheliometric disturbance from Tarawera appear only as a retardation in the recovery from Krakatoa.

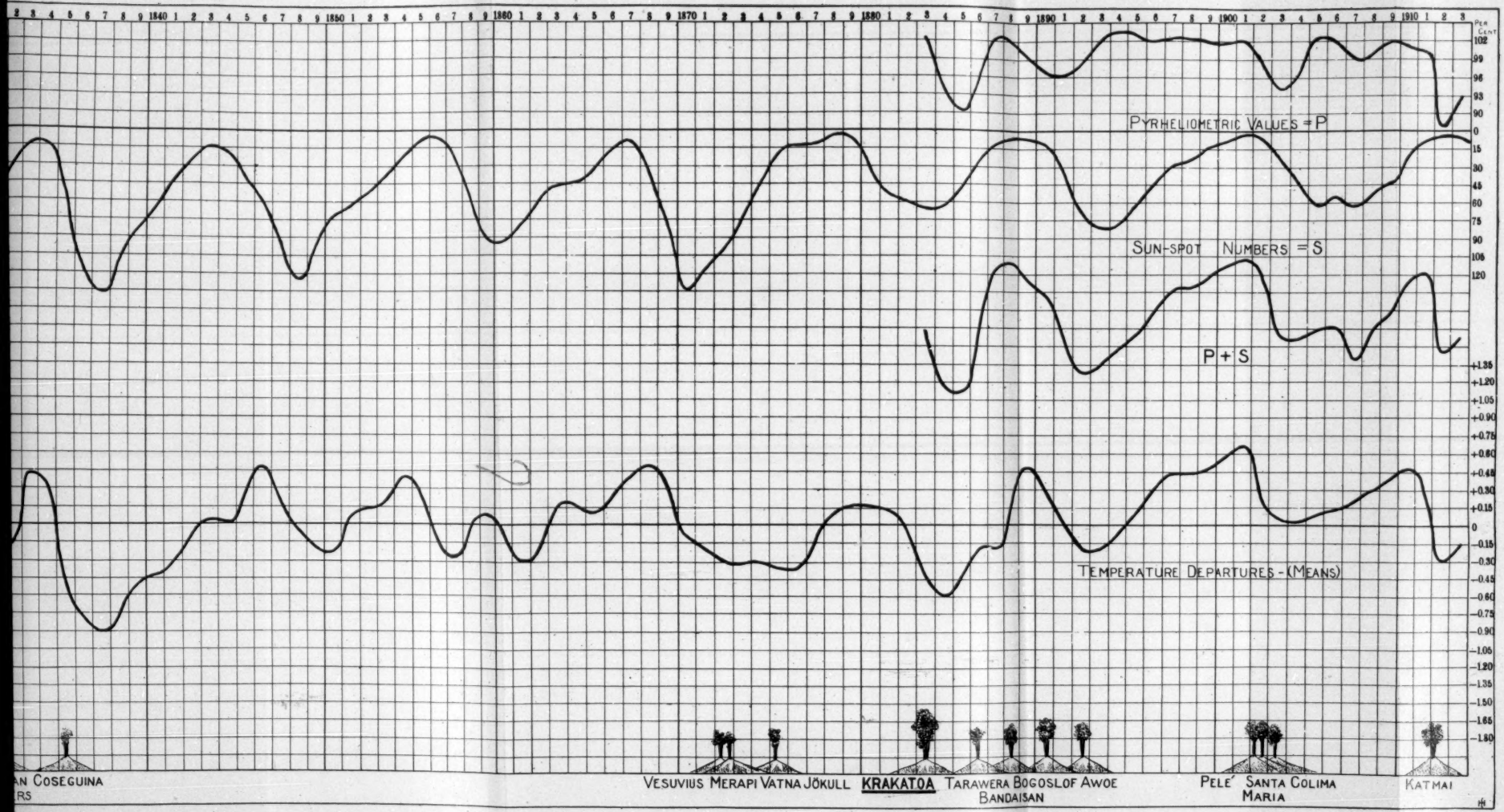
Neglecting the smaller irregularities which may or may not have been of world-wide occurrence, and remembering that, other things being equal, we may expect temperature maxima at the times of spot minima and temperature minima at the times of spot minima, we can tabulate as follows the marked discrepancies and their probable explanations:

[34] Schneider, Die Vulcanischen Erscheinungen der Erde, p. 1, 1911.
[35] Rept. Krakatoa Committee Royal Society, 1888, p. 393.



Relations of pyrheliometric values and mean temperature de

G. 5.



artures to sun-spot numbers and violent volcanic eruptions.

TEMPERATURE AND SUN-SPOT DISCREPANCIES.

Date	Nature of discrepancy.	Probable cause.
1755–6	Cold.	Kötlugia, Iceland, 1755.
1766–7	Cold.	Hecla, Iceland, 1766.
		Mayon, Luzon, 1766.
1778–9	Warm.	Maximum number (annual) of sun-spots ever recorded and unusually short spot period. Can it be that the solar constant actually was distinctly greater than usual at this time?
1784–5–6	Cold.	ASAMA,* Japan, 1783. The most frightful eruption on record.
		Skaptar Jökull, Iceland, 1783.
		Vesuvius, Italy, 1785.
1799	Cold.	Fuego (?), Guatemala. (Uncertain.)
1809	Cold.	St. George (?), Azores, 1808. (Uncertain.)
		Etna (?), Sicily, 1809. (Uncertain.)
1812–13–14–15–16	Cold.	Soufrière, St. Vincent, 1812.
		Mayon, Luzon, 1814.
		TOMBORO, Sumbawa, 1815, very great.
1831–2	Cold.	Graham's Island, 1831.
		Babujan Islands, 1831
		Pichincha, Ecuador, 1831.
1856–7	Cold.	Cotopaxi (?), and others, 1855–6. (Uncertain.)
1872–3	Cold.	Vesuvius, Italy, 1872.
		Merapi, Java, 1872.
1875–6	Cold.	Vatna Jökull, Iceland, 1875.
1884–5–6	Cold.	KRAKATOA, Straits of Sunda, 1883, greatest since 1783.
		Saint Augustin, Alaska, 1883.
		Tarawera, New Zealand, 1886.
1890–1–2	Cold.	Bogoslof, Aleutian Islands, 1890.
		Awoe, Great Sangir, 1892.
1902–3–4	Cold.	Pelée, Martinique, 1902.
		Santâ Maria, Guatemala, 1902.
		Colima, Mexico, 1903.
1912–13	Cold.	Katmai, Alaska, 1912.

* This type indicates exceptional violence.

The above list does not dispose of all the seeming irregularities, nor of all the known volcanic eruptions; but it does dispose of all the well-defined and unquestioned irregularities and also of every one of the known really great volcanic explosions since 1750.

We may conclude, therefore, that the variations in the average temperature of the atmosphere depend jointly upon volcanic eruptions, through the action of dust on radiation, as already explained, and upon sun-spot numbers, through, presumably, some intermediate action they have upon the atmosphere—possibly of the nature we shall now explain.

How Sun-spots May Change Earth Temperatures.—If the solar constant remains the same from spot maximum to spot min-

imum it clearly is not easy to see at a glance why the surface temperature of the earth should vary as it does with spot numbers; and the situation is still more difficult if, as observations appear to indicate, our lowest temperatures occur when the solar constant is greatest and our highest temperatures when this constant is least! There is, however, a possible explanation of the paradox, and, while it may not contain the whole truth, it nevertheless is sufficient to show *a priori* that in all probability our temperatures do change from spot maxima to spot minima without a corresponding change in the solar constant, and also to show that a decrease in our surface temperatures may accompany even a slight increase in the solar constant.

The explanation in question has already been given elsewhere,[36] and the original paper must be consulted by those who wish to weigh all the details of the argument. Briefly, however, the argument is as follows:

1. At the times of spot maxima the solar corona is much more extensive than it is at the times of spot minima—a well-known observation.

2. This corona consists, in part at least, of reflecting particles, as many eclipse observations have shown, and so may be regarded as dust in the solar atmosphere.

3. The brightness of the sun, as every solar observer knows, drops off from centre to limb.

4. This drop, as reported by various observers, is greater the shorter the wave-length, and due, almost certainly, to diffuse scattering.

From the observational facts it follows that during spot minima, other things being equal, the solar spectrum must necessarily be richer in violet and ultra-violet radiation than it is during spot maxima.

But, as experiment has shown,[37] ultra-violet radiation of shorter wave-length than λ 1850 is strongly absorbed by oxygen, with the result that some of the oxygen is converted into ozone. Hence since the atmosphere of the isothermal region is cold and dry (conditions favorable to the stability of ozone), and since of the gases of the upper atmosphere only oxygen is appreciably

[36] Humphreys, *Astrophys. Jr.*, 32, p. 97, 1910.
[37] Lyman, *Astrophys. Jr.*, 27, p. 87, 1908.

absorptive of radiations between λ 1250 and λ 1900,[38] we should confidently expect it to contain more or less ozone, an expectation greatly strengthened by the observations of Fabry and Buisson,[39] though already virtually confirmed by Ångström.[40] In so far then as this ozone is produced by the action of ultra-violet solar radiation, we should also very definitely expect it to be greater in quantity when the short wave-length radiation to which it is due is most intense, or, presumably, therefore, at the times of spot minima. Now, according to the experiments of Ladenburg and Lehmann,[41] while ozone is somewhat absorptive of solar radiation it is several-fold more absorptive, in fact highly absorptive, of terrestrial radiation. Hence in this case, as in the case of the absorption of radiation by dust, already considered, equation *A*, page 139, is applicable.

In this equation let a be the coefficient of absorption of the ozone in the isothermal region for solar radiation, and b its coefficient of absorption for earth radiation. To be definite, let $a = 0.02$ and $b = 0.10$ at the time of a spot maximum, and for a spot minimum let $a = 0.03$ and $b = 0.15$, quantities that would require really very little ozone. Then, remembering that the earth radiates practically as a full radiator, or black body, at the absolute temperature 256° C., and taking $T_{max.}$ and $T_{min.}$ as the equilibrium temperatures at the time of spot maximum and spot minimum respectively, we get

$$\left(\frac{T_{max.}}{256}\right)^4 = \frac{521}{500}; \quad T_{max.} = 258°.65.$$

and

$$\left(\frac{T_{min.}}{256}\right)^4 = \frac{2129}{2000}; \quad T_{min.} = 260°.05.$$

That is, under these conditions, and if the solar constant should remain exactly the same, the temperature at the time of spot minimum would be 1°.4 C. warmer than at the time of spot maximum. Hence, even a slight increase in the solar constant at the time of spot maximum might still leave the temperature a trifle cooler than at the time of spot minimum.

[38] Lyman (*l. c.*).
[39] C. R., 156, p. 782, 1913; *Journal de Physique*, 3, p. 196, 1913.
[40] *Arkiv för Matematik, Astronomi och Fysik*, 1, p. 395, 1904.
[41] *Annalen der Physik*, 21, p. 305, 1906.

Of course, it is not claimed that the above gives, both quantitatively and qualitatively, exactly what happens, but it is claimed that it does show qualitatively what might happen, and, so far as we can judge from observations and laboratory experiments, what actually must happen.

Influence of Carbon Dioxide on Temperatures.—It was stated in the early part of this paper, under the carbon dioxide theory of ice ages, that the question of the possible effect a change in the amount of carbon dioxide in the atmosphere might have on temperatures would be taken up later. The way to this is now open through the above discussion of ozone. Like ozone, carbon dioxide also is more absorptive of terrestrial radiation than of solar energy. Hence increasing the carbon dioxide in the atmosphere, and thereby increasing its amount in the isothermal region where we can treat it as a shell external to the radiating earth, obviously must have the same general effect on the temperature of the earth as increasing the ozone of this region would have. That is, other things being equal, a greater or less temperature increase would follow the introduction into the atmosphere of a larger amount of carbon dioxide.

Because of the constant mixing caused by vertical convection it is probable that the percentage of carbon dioxide is very nearly as great at the under surface of the isothermal region as it is at the surface of the earth. If so, then the carbon dioxide of the isothermal region is equivalent, roughly, to a layer 40 centimetres thick at normal atmospheric pressure. In high latitudes, where the isothermal level is low, the equivalent layer probably is thicker than this, and in equatorial regions probably thinner. Now, according to the experiments of Schlaefer,[42] a layer of carbon dioxide 40 centimetres thick is sufficient to produce very nearly full absorption, and therefore no increase in the amount of carbon dioxide in the atmosphere could very much increase its temperature.

An approximate idea of the possible temperature change of the lower atmosphere as a result of the presence of carbon dioxide in the isothermal region can be obtained from known data. Thus Abbot and Fowle[43] have computed that carbon dioxide

[42] *Ann. der Physik*, 16, p. 93, 1905.

[43] Annals Astrophys. Obsy., Smithsonian Inst., vol. 2, p. 172, 1908.

may absorb 14 per cent. of the radiation from a black body at the temperature of 282.2° C. absolute. But as this is not many degrees, 25 or so, above the effective temperature of the earth as a radiator, it follows that 14 per cent. is, roughly, the upper limit to which terrestrial radiation can be absorbed by carbon dioxide in the isothermal region, while its absorption of solar radiation is very nearly negligible.

Assuming that the present amount of carbon dioxide in the isothermal region absorbs 1 per cent. of the solar radiation and 10 per cent. of the outgoing earth radiation (values that seem to be roughly of the correct order), and using equation *A* as above, it will be seen, if the experiments here referred to and the assumptions are substantially correct, that doubling or even multiplying by several-fold the present amount of carbon dioxide could increase the average temperature by no more than about 1.3° C. Similarly, reducing the carbon dioxide by one-half could decrease the temperature by no more than approximately the same amount, 1.3° C.

It is not certain to what extent the percentage of carbon dioxide in the atmosphere has actually varied during the geological past, but, if the above reasoning is correct, it seems that our surface temperatures could never have been much increased above their present values through the action of this particular agent alone. Further, the fact, so far as known, that within the tropics, at least, plant growth, even during the ice ages, was quite as vigorous during the past as it is at present, shows that for many ages carbon dioxide has been abundant in the atmosphere—probably never much less abundant than at present. Hence it seems likely that a decrease in temperature of a fraction of one degree is all that can reasonably be accounted for in this way.

Finally, if the above reasoning is correct, it seems that changes in the amount of carbon dioxide in the atmosphere might have been a factor in the production of certain climatic changes of the past, but that it could not, of itself, have produced the ice ages.

Having considered, in the above long digressions, the observational evidence of temperature changes in connection with volcanic explosions, we are ready again to take up the main sub-

ject and to consider one or two more of the physical problems it presents.

Number of Dust Particles.—The intensity of the solar radiation I_x after it has passed through x centimetres of the dust layer of the atmosphere is given, as we have seen, by the equation

$$I_x = Ie^{-2\pi\pi x (92)^2 \times 10^{-12}}$$

But, according to numerous observations made during the summer and fall of 1912, when the solar radiation had passed entirely through the dust layer at such an angle that it met, roughly, twice as many dust particles as it would have met had it come in normally, or from the zenith, it was reduced by about 20 per cent. That is to say, under these conditions

$$I_x = 0.8\, I.$$

Hence

$$10 = 8e^{2\pi x\pi (92)^2 10^{-12}}.$$

Let $nx = 2N$, the total number of particles passed in a cylinder of one square centimetre cross section. Then

$$10 = 8e^{4N\pi (92)^2 10^{-12}}.$$

Hence the number of particles in a vertical cylinder of one square centimetre cross section is given, roughly, by the equation

$$N = 34 \times 10^4.$$

Temperature Correction Due to Dust Radiation.—With the number and size of the dust particles we are in position to determine at least an upper limit to the effect of the direct radiation of the particles themselves on the temperature of the earth.

The temperature of the dust particles, obviously, is very nearly that of the upper atmosphere in which they float and therefore, as we have seen, approximately $-55°$ C., or $218°$ C. absolute. As we have also seen, the quantity of radiation from the atmosphere below the isothermal region is substantially that which would be given off by a full radiator at $256°$ C. absolute.

Now assume the dust particles to be concentrated side by side on a common plane, and further assume them to be full

radiators—conditions that would raise their effect to the theoretical upper limit. Let E be the intensity or quantity per square centimetre of the outgoing planetary radiation, and D the intensity of the incoming dust radiation. Then

$$E : D = (256)^4 : a\,(218)^4,$$

in which a is the projected area of all the particles in a vertical cylinder of one square centimetre cross section.

But

$$a = 34 \times 10^4\,(92)^2\,10^{-12} = 9 \times 10^{-3}.$$

Hence

$$E = 211\,D.$$

Now when the radiation D is absorbed by the lower atmosphere it follows that its temperature will be so increased that, when equilibrium is reached, the intensity of its new radiation will be to that of its old as 212 is to 211. Hence ΔT, the effective temperature increase of the lower atmosphere, is given by the equation

$$\frac{(256 + \Delta T)^4}{(256)^4} = \frac{212}{211},$$

from which

$$\Delta T = 0°.3\ \text{C.}$$

But, as stated above, the dust particles, presumably, are not full radiators, and therefore probably one-fifth of a degree C. is as great an increase in temperature as may reasonably be expected from this source. But this *increase*, 0.2° C., is small in comparison with the *decrease*, 6° C. to 7° C., caused by the interception of solar radiation, already explained. Hence it appears reasonably certain that the sum total of all the temperature effects produced by volcanic dust in the upper atmosphere must be, if long continued, a lowering of the surface temperature by several degrees C.

Total Quantity of Dust.—Let $nx = 2N$, the total number of particles passed in a cylinder of one square centimetre cross section. Then

$$10 = 8e^{4N\pi}\,(92)^2 \times 10^{-12}.$$

Hence

$N = 34 \times 10^4$ roughly = number of particles in a vertical cylinder of one square centimetre cross section.

If A is the entire area of the earth in square centimetres, then the total number of dust particles is

$$NA = 1734 \times 10^{21}.$$

But the radius of each particle is 92×10^{-6} cm., and its volume, assuming it spherical, 33×10^{-13} cubic centimetres. Hence the total volume of the dust, assuming the particles spherical, is equal, roughly, to a cube 179 metres, or about 587 feet on the side, an amount that certainly is not prohibitively large.

As just stated, the total quantity of dust sufficient, as we have seen, to cut down the intensity of the direct solar radiation by 20 per cent., and therefore, if indefinitely continued, capable, presumably, of producing an ice age, is astonishingly small,—only the 174th part of a cubic kilometre, or the 727th part of a cubic mile, even assuming that the particles are spherical. Since, however, in large measure, the particles are more or less flat, as already explained, it follows that the actual total mass of the dust necessary and sufficient to reduce the intensity of direct solar radiation by 20 per cent. probably is not more than the 1500th part of a cubic mile, or the 350th part of a cubic kilometre.

Hence, even this small amount of solid material distributed once a year, or even once in two years, through the upper atmosphere, would be more than sufficient to maintain continuously, or nearly so, the low temperature requisite to the production of an ice age; nor would it make any great difference where the volcanoes productive of the dust might be situated, since, from whatever point of introduction, the winds of the upper atmosphere would soon spread it more or less evenly over the entire earth.

A little calculation will show, too, that this quantity of dust yearly, during a period of 100,000 years, would produce a layer over the earth only about half a millimetre, or one-fiftieth of an inch, thick, and therefore one could hardly expect to find any marked accumulation of it, even if it had filled the atmosphere for much longer periods.

Inherent Ability of the Earth to Produce its Own Climatic Changes.—Whether periods of explosive volcanic activity—and in this case, since the locality of the volcano is a matter of small importance, the whole earth must be considered—occurred at such times as to synchronize with the ice ages and with other

epochs of great climatic change is, of course, a problem for the geologist to solve. May it be that extensive upheavals and great volcanic activity were synchronous? If so, their climatic effects must have been additive. Increase in land elevation would, because of the resulting decrease in temperature, extend the area of snow and ice, and the snow, in turn, through its power to reflect sunlight, would decrease the amount of solar energy actually absorbed, and thus still further extend the ice sheet, and so on through an indefinite though decreasing and limited series. Besides, an elevation of any considerable extent is pretty certain to be accompanied by increase in continental area and radical modification of shore lines, such that greater or less changes would follow in the direction, temperature, and magnitude of ocean currents, location, number, and intensity of the permanent "highs" and permanent "lows," direction and force of local winds, amount of local precipitation, and a host of other meteorological phenomena. Thus, as the oceans and continents are now related to each other the main drift of warm water from the tropics is toward the north and not toward the south, but a change in the relation of land and water that would reverse this proportion obviously would have the result of leaving the northern hemisphere, especially in higher latitudes, perceptibly colder than it now is, and of producing many other climatic changes, all of which it would be interesting to discuss from the standpoint of modern meteorology, though that would be beyond the restricted purpose of this paper—a consideration of the climatic effects of volcanic dust.

It is surmised, therefore, that the greatest of our past climatic changes may have been caused by the combined and, roughly, simultaneous variations in continental level and volcanic activity; cold periods coming with increase in elevation and increase in vulcanism, minor climatic oscillations with temporary changes in vulcanism, and warm periods when the land had gone back to low levels and volcanoes had ceased greatly to veil the skies with dust. But while great changes in level, such as probaby have several times occurred, and great changes in vulcanism, such as also have occurred, would, even separately, produce climatic changes, it remains for the geologist to determine just what was the relation of these phenomena to each other and to the great climatic changes with which he is so deeply concerned.

However, this much appears well-nigh certain: Since the beginning of reliable records, say 160 years ago, the average temperature of the earth has been perceptibly lower, possibly as much as 1° F., than it would have been if during all this time there had been no volcanic explosions violent enough to put dust into the isothermal region of the atmosphere. Similarly, on the other hand, if, during this period, violent volcanic explosions had been three or four times more numerous than they actually were, our average temperatures probably would have been at least 2° F. to 3° F. lower, or low enough, if long continued, to bring on at least a moderate ice age.

As already stated, it may be that our great climatic changes have been caused by corresponding changes in the output of solar energy, though at present this seems wholly impossible either definitely to prove or clearly to disprove; but, however they actually were produced, it is probable, if not entirely certain, that, given an invariable or nearly invariable solar constant, the earth itself possesses potentially the power of bringing about its own climatic changes—even of beginning and of ending its own ice ages, and its own periods of genial climates.

Magnitude and Importance of Actual Temperature Changes..—The actual temperature range from sun-spot maximum to sun-spot minimum varies, roughly, from 1° F. to 2° F., or possibly more, while the effect of volcanic dust appears to be fully as great—on rare occasions even much greater. In some ways, and in respect to many things, a range of average temperatures of 2° F. is well-nigh negligible, and therefore, however important the results may seem to the scientist, the ultra utilitarian would be justified in asking, "What of it?"

Much of it, in a distinctly practical as well as in a purely scientific sense, as is true of every fact of Nature. For instance, during the summer or growing season a change of 1° F. produces a latitude shift of the isotherms by fully 80 miles. Hence, if there is but little or no volcanic dust to interfere, during sun-spot minima cereals and other crops may successfully be grown 50 to 150 miles further north (or south in the southern hemisphere) than at the times of sun-spot maxima. This alone is of great practical importance, especially to those who live near the thermal limits of crop production.

In addition to changing the area over which crop production is possible, a change of average temperature also affects, in some cases greatly, the time of plant development. Thus Walter [44] has shown that a change of only 1.26° F. may alter, and in Mauritius has been observed actually to alter by as much as an entire year, the time required for the maturing of sugar cane. Hence the temperature changes that normally accompany sun-spot variations, though small in absolute magnitude, are of great importance, and, by availing ourselves of the reasonable foreknowledge we have of these changes, may easily be made of still greater importance.

In forecasting these small but important climatic changes it must be distinctly remembered that to the fairly periodic and therefore predictable, sun-spot influence must be added the irregular and unpredictable volcanic effects. But even here the case is not bad for the forecaster, since the volcanic dust always produces, qualitatively, the same effect—a cooling—and since both the amount of this cooling and its duration may approximately be estimated from the nature of the volcanic explosion itself.

CONCLUSION.

It has been shown in the above, among many other things, that volcanic dust in the high atmosphere decreases the intensity of solar radiation in the lower atmosphere, and therefore the average temperature of the earth, substantially as theory indicates *a priori* that it should; and this effect has been clearly traced back to 1750, or to the time of the earliest reliable records. Hence it is safe to say that such a relation between volcanic dust in the upper atmosphere and average temperatures of the lower atmosphere always has obtained, and therefore that volcanic dust must have been a factor, possibly a very important one, in the production of many, perhaps all, past climatic changes, and that through it, at least in part, the world is yet to know many another climatic change in an irregular but well-nigh endless series—usually slight, though always important, but occasionally it may be, as in the past, both profound and disastrous.

[44] "On the Influence of Forests on Rainfall and the Probable Effect of "Déboisement" on Agriculture in Mauritius (1908).

THE ELECTRICAL EQUIPMENT OF A MODERN BATTLESHIP.[1]

BY

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ONE of the reasons underlying the appropriation of large sums of money by civilized nations each year for the construction of ships of the line is an endeavor to define and produce the modern battleship. Time in which to execute this work, and the development of the arts and sciences, act to defeat this purpose. A period of about four years is required to prepare the design and construct the vessel; and during this time only small changes in equipment can be made.

Although the electric plant of a battleship is a small part of the whole equipment, yet, like the nerves of the human body, it comes in contact with every part. As the work of installation requires about one year, and obviously cannot be commenced until the structure of the vessel is prepared for its reception, it is possible to give careful consideration to details. So rapid, however, are the improvements in the art and practice of electricity that the latest commissioned battleship hardly satisfies the term modern.

The substance of this paper, therefore, will be suggestive rather than historical. The intention is to suggest certain modifications to the present equipment, based on land usages and their adaptation for marine purposes. This will occasion reference to the practice of many nations, and will, so far as the writer knows, set forth an electrical equipment installed at the present time by none.

GENERATION OF ELECTRICITY FOR LIGHTING AND AUXILIARY POWER.

On the question of the centralization, or the distribution of the generating sets, opinions differ. To put all your eggs in one basket when you are going into battle would appear to favor separation or distribution, but it would seem ridiculous to value the electric plant above that of the propelling machinery.

[1] Presented at the joint meeting of the Electrical Section and the Philadelphia Section, American Institute of Electrical Engineers, held Thursday, April 3, 1913.

Though separated by a bulkhead, the main engines are practically in one compartment, protected under water by cellular water-tight compartments. An under-water attack might cripple these engines and so disturb the steam conditions that the electric plant, though preserved, would be of little value. It may be said, on the contrary, so long as you have electricity and can operate your guns with this power, just so long you may fight.

In the future there will be developed a generating unit which is not dependent upon the same source of power as the propelling machinery. Then a small unit may be installed in each turret in order that the turret may, in a sense, become a self-contained fortress. This would provide the very best strength for the man-of-war.

There is only one more matter for consideration in this discussion, and that a curious one. On land we are comparatively free in the paralleling of generators, and think little of "throwing in" another generator into the general network of the distributing system; but on war vessels the complications for effecting such operations do not seem to please, and in many cases positive preventative measures are taken to avoid its possible occurrence. Like most of the applications of electricity, it has not been without trial, and the performance, from all reports, was satisfactory.

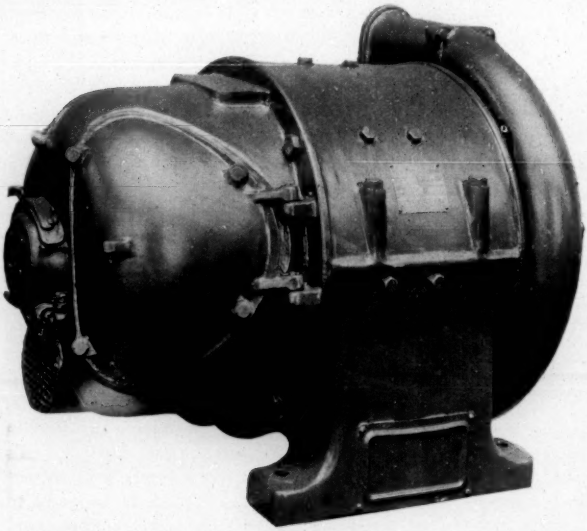
Given the sum of your lighting, battle, and power load, and the total kilowatt capacity is settled. Then arises the question of size of unit. The largest unit, to the author's knowledge, now furnished is 375 kilowatts. With units of this size a fairly economical arrangement for ordinary day and night loads, with a safe battle reserve, can be worked out. It is most desirable to provide a spare unit for battle conditions, for no one can conceive of the possible exigencies of war. If the electric plant of war vessels has doubled in the last decade we may well expect a like increase in the future. As the development of auxiliary apparatus continues so will the daily load be added to, and it may be expected that very shortly 500-kilowatt generators will be placed in service.[2]

[2] Some European powers install small oil engine-driven generators for use when the vessel is in harbor. This permits the drawing of the fires, allowing the boilers to be cleaned and repaired. This outfit is of such size, approximately 150 kilowatts, that not only the ordinary loads but also the gun practice loads may be carried.

Direct current is universally employed, due to the early development of suitable apparatus and because we are all so familiar with it. It is reported vaguely that some European nation has made trial of a mixed alternating current-direct current system on some small craft, but definite results of such an equipment are not available. Our British brothers, with a 3-wire system, use 110 volts for lighting, and operate their motors on 220 volts from the outer wires. In this country we stepped up and down in voltage about eleven years ago. In 1899 the *Kearsarge* and *Kentucky* were wired for 80 and 160 volts. In 1902 our Government adopted, in accordance with the standardization rules of the A. I. E. E., a voltage of 125. Our Japanese friends hold to a voltage of 50. In contrast, we find the new Argentine battleships provided with 220 volts on a straight 2-wire system. This choice of voltage is based on the development of the incandescent lamp. The lighting system for this period has been the sole consideration for the use of electricity. The increased use of electric motors has now changed the problem almost to the extent of making the lighting system of secondary importance.

This ever-increasing motor load must be the subject of thought to-day; and with it comes the necessity for economy in fuel consumption and reduction in weight. Even in our present steam-propelled vessels the use of electricity for the economical operation of auxiliaries presents a large field. It was only a few years ago that this modern power entered the domain of the steam engineer in the form of forced-draft fans; but this was quite sufficient to convince him of the benefits well present in the mind of the electrical engineer. Electricity is ready to furnish power for air-pumps, water circulating pumps, and eventually that difficult application—boiler-feed pumps. In the deck department already such applications as the anchor windlass and steering gear have been made, and we can expect that with these fully accomplished further applications will present themselves. With this problem before us, and the question of transmission set aside for the present, would it be reasonable to consider the use of alternating current instead of direct current? There is no doubt that an increase of voltage with direct current will help conditions; but it will not completely solve the problem or give that flexibility for expansion that alternating current inherently possesses. Of course, a hasty jump to a higher voltage

would doubtless frighten all parties interested, but we are referring to not a low potential but an insignificant one from the viewpoint of present land practice. There would be little gained by using 125 volts direct current; but why should not the alternating current voltage be taken very much higher? Our knowledge of insulation and the manufacture of insulating



Type of totally enclosed, ventilated, splash-proof, split-frame motor used in connection with pumps for flushing purposes. This is a special design prepared to reduce the size of motor and retain the necessary horsepower. Rated capacity of motor, 35 horsepower, 1200 revolutions per minute, 220 volts.

materials has followed the developments of land practice, and the writer believes that we are able to cope with this question aboard ship.

Control of generating sets aboard ship is not difficult, and there seems some uniformity with remote control coming into its share of consideration. This latter operation should be entirely automatic and fool-proof. It is unquestionable that the automatic operation of switches, circuit breakers, rheostats, etc.,

has gained such a reliable place in the opinion of land engineers that the application of this apparatus to shipboard is entirely reasonable. Provided with pilot lights and mechanical signals, a bench board as installed in many of our large central stations would be an engineering advance and also of importance from a military point of view, where the elements of time and order are principal factors.

AUXILIARIES.

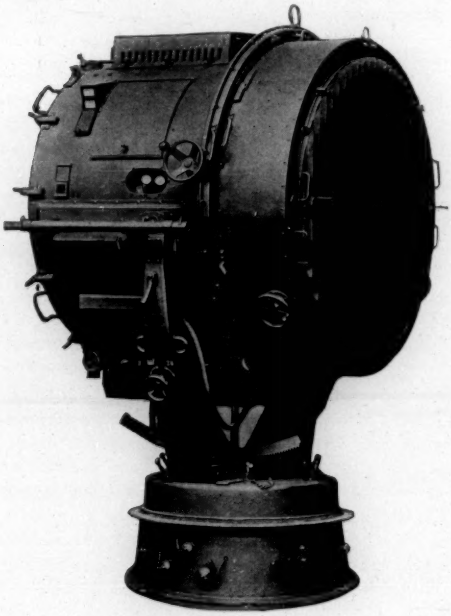
The lighting of a vessel is really an auxiliary, and should have due consideration, although now passing into second place compared to power. There is a growing confidence in the wire-drawn tungsten lamp for all lighting purposes, superseding the arc lamp for large spaces and coaling ship—this latter, of course, not being essential to an oil-burning vessel. Carbon filament lamps may still preserve their usefulness in and about compartments where machinery causes severe vibration. It speaks well of the manufacture of tungsten lamps when their reliability is so highly valued that all spring-type lamp sockets are being rapidly replaced by the ordinary commercial type. This practice is now adopted by nearly all nations. Large single unit lamps are used for boiler rooms, engine rooms, and gangway lamps.

Searchlights still hold an important place in this installation, and the practice of each nation seems to oscillate between a large number of fair size, say 30- or 40-inch, and a small number of large size, say 60-inch. Experiments are now proceeding in England on the deposition of gold to produce an effective mirror instead of silver. The former has many points in its favor: it is not affected by chemical or climatic conditions, more effective in foggy weather, due to large percentage of red and yellow rays, absence of halos, and is an easier light for distinguishing shades of gray.

For convenience, electric heating is classified as power, due, no doubt, to its present modest application. It is foreseen that it will in time achieve a more distinctive place in the equipment. At present electric ranges, bake-ovens, and radiators are installed and are giving good return for their introduction. They furnish a heavy part of the cruising load, and probably will be a reason for increasing the size of generating units. This application is

so young that there can be no positive statement made, yet the rapid improvements already seen give promise of greater applications in the future.

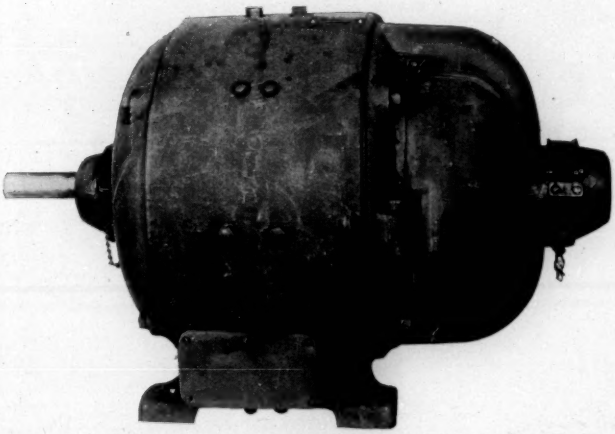
Approximately 100 kilowatts maintain the lighting system, and the balance of the 1500 kilowatts is then available for power



Electrically-controlled searchlight, permitting operation at a distance. The signalling shutter may also be automatically operated at a remote point.

purposes. This is divided roughly into auxiliaries that are used only when cruising, or at anchor, or in port; those used in battle only; and those which lap over and are used in both cases. To go backwards, the steering gear would be used while in battle as well as when cruising; the turret machinery would be used only in battle; and the anchor or windlass would be used

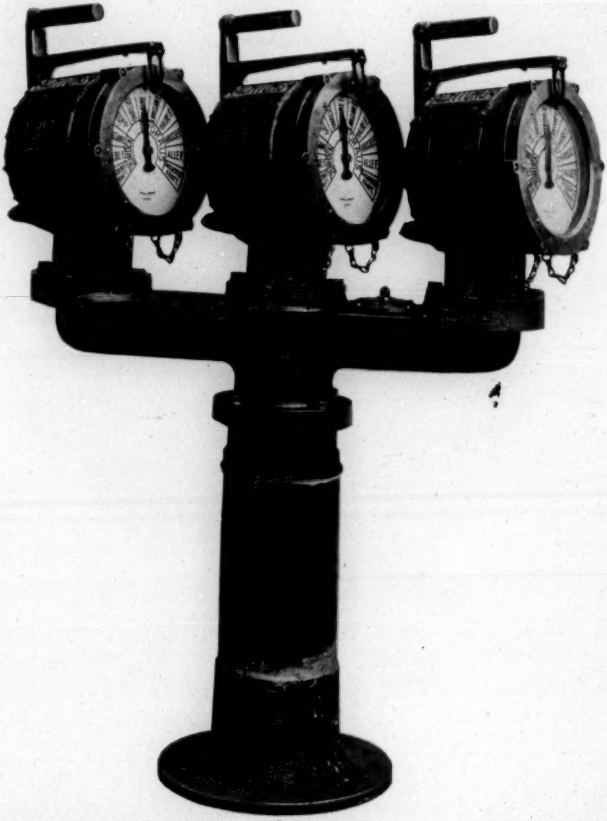
only when about to weigh anchor. The problems of design for all these auxiliaries are extremely interesting not only to the electrical engineer from the electrical features, but also because of the military questions involved. These auxiliaries have a great bearing on the above suggested change from direct current to alternating current. The question of speed control arises, but, as a matter of fact, it is of little moment. Every application of a direct-current motor could be just as readily met with the alternating-current motor; and for the most part with the squir-



Type of totally enclosed, water-tight, direct-current motor. Note water-tight box arranged for protecting the terminals and providing proper facilities for entering feeders.

rel-cage induction motor. Where great variations of speed are needed they will be found in some minor application, not in the significant ones. A marked improvement recently is the increasing use of contactor control, which enables the vital parts of the control to be placed below the weather deck where it can be easily cared for and will not be endangered when the vessel is subjected to the enemy's fire. This feature of remote control gives an added weight and importance to the electric motor application, which is seen in its sharpest outline by the revival of the electric steering gear. It is expensive to lead piping all over a vessel, but

there is no hardship attached to the running of a comparatively small cable. It is then possible to steer the vessel in many

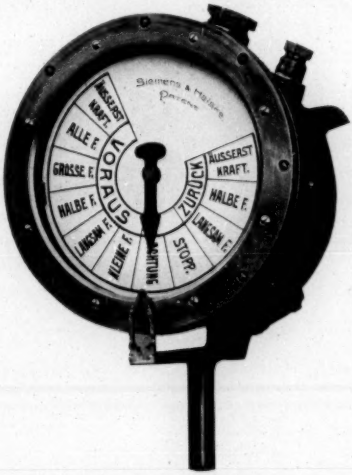


Electric engine telegraph transmitters for communication between the bridge and the engine room. The three transmitters connect separately to receivers located in their respective engine rooms. Instruments are arranged for reply signal.

places; and in the case of emergency the transfer from one place to another can be made in a very small fraction of time.

The signalling system is another important and extensive

auxiliary on a modern man-of-war. It now very nearly equals in cost the power and lighting systems. Following the service it performs, it is divided into many subdivisions, comprising telephones, telegraphs, call-bells, voice-tubes, control of gun-fire, etc.[3] Although mechanical telegraphs are still retained for the main signals for manœuvring the vessel, establishing com-



Electric Engine Telegraph Receiver.—One of these instruments is located in each engine room and connected with transmitter on bridge, in conning tower, and in central station.

munication between the bridge and the engine room, yet electrical instruments parallel them and perform all other means of communication. Between important stations the electrical signal is also associated with the voice-tube. Electrical telegraphs were designed first for the use of small electric lamps illuminating orders or numbers marked upon a transparent dial. Various methods of actuating armatures by means of magnets have been experimented with, and some of these have been tried

[3] Wireless telegraphy and telephony should be mentioned in this connection because of the general interest in this application. As such apparatus requires the use of alternating current, the suggestions in this paper are advantageous.

with uncertain success; but no instrument employing a "step-by-step" motion would seem serviceable for this duty. The accidental interruption of the supply or failure in some one indicator would affect the synchronous operation of all the indicators, thereby defeating the purpose of the signal. So development to-day is on the motor principle, with instruments designed for either direct or alternating current. Neither of these systems has been in service long enough to judge of their respective merits; but such apparatus, if of equal reliability, will succeed the lamp type by virtue of the reduced installation cost and the avoidance of "no signal" caused by defective lamps.

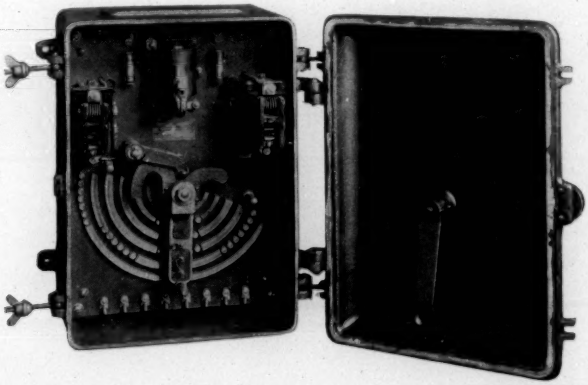
Before passing on to the subject of distribution it may be of interest to note the reduction in weight of electric auxiliaries that would come about from the suggestion made above to replace the direct-current motors by alternating-current motors. Only an approximate comparison can be given between a 125-volt direct-current equipment and a 230-volt alternating-current equipment. The former apparatus having been in service for years, and the latter not yet applied, requires that we use the weight of alternating-current land apparatus, judiciously increased to compensate for marine service. We find that the weight of direct-current apparatus amounts to 890,000 pounds, and that of the alternating-current apparatus 690,000 pounds, making a difference of 200,000 pounds, or approximately 89 tons.

SYSTEMS OF DISTRIBUTION AND METHODS OF INSTALLATION.

For many years England held closely to the single-wire ground-return system; but to-day the ring system is in favor. This is only used for lighting and minor power circuits, and could hardly be extended to the larger power applications, because it does not admit of sufficient control to conveniently manipulate the generators. The main circuits pass from the switchboard along one side of the vessel around to the other side, returning again to the switchboard. These feeders are broken by section boxes, from which sub-circuits are led to distribution panels for the branch lighting circuits. Other nations prefer greater control for lighting purposes and hold to the 2-wire system with group feeders. These feeders are further subdivided into mains terminating at distribution panels equipped with switches and fuses, from whence are led away branches

to groups of lights. In this way separate feeders are designated for battle purposes only and others for ordinary lighting, in order that there may be no possibility of the misuse of light during a night engagement. Naturally, where two direct-current voltages are used the system would be a 3-wire one, employing the one outer and the neutral for lighting and the two outers for power.

In a proposal for 3-phase, 230-volt alternating-current distribution three wires would be used for all power circuits, and

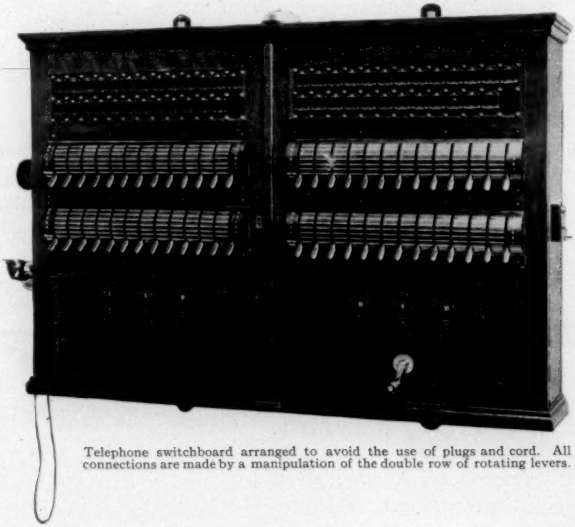


Interior view of field-control motor panel, showing again the compactness of construction, method of insulation, and the mechanical construction necessary for providing manipulation without removing cover.

the lighting could be taken from one phase so as to retain the low-potential incandescent lamp. There seems to be no reason, however, why the 230-volt tungsten lamp should not be employed with advantage. As battleships have increased in weight and dimensions they may grow to such size that requirements for higher potential will become a necessity, and then the three-phase distribution will be more economically accomplished by using four wires with resultant flexibility.

The methods of installation for marine service differ considerably when comparing the practice of the various nations. England uses lead-covered cables fastened directly to the bulk-

heads and decks by brass clips; Germany uses a lead-covered and steel-armored cable; and until recently our navy held firmly to a conduit system lightened by running well-protected leads without any covering over the rubber or braid, supported on porcelain insulators. Where any danger existed due to mechanical injury the cables were encased in steel. Foreseeing the advantages to be gained by the use of lead-covered, steel-armored cables, our navy has now adopted this construction for all future ships of the line.



Telephone switchboard arranged to avoid the use of plugs and cord. All connections are made by a manipulation of the double row of rotating levers.

For 2-wire distributions, either alternating current or direct current, this type of construction permits the use of twin conductors up to and including 60,000 C. M. Beyond this size single conductors of the same design are employed. In considering the 3-phase alternating-current system, 3-wire cables with lead and armor are prepared in order to obviate induction in interior-communication circuits and to prevent the effects of self-induction. It is not believed that, in the usual runs on ship-

board, the reactive effect of the steel braid will be harmful. If we increase the voltage from 125 to 230 volts and then compare the advantages of the alternating-current, 3-wire, 3-phase system, although we must take into consideration the power factor, we will find a large saving in weight, accompanied by a corresponding reduction in first cost of installation.

On two equal systems changing from a mixed conduit and "open-wiring" installation to that of steel-armored, lead-covered cables we find about an equal cost of installation at the present time, due to the lack of development of the art, and also to the necessity of skill in the working of this material on the vessel. A few years of practice, coupled with the design of proper tools, will reduce the cost in favor of steel-armored, lead-covered cables. Decidedly the largest gain and best reason for its adoption are the reduction in cost of maintenance and the freedom from grounds. Reports of vessels so equipped now in service for the past 17 or 18 years confirm the opinion that grounds will be found only at connection points, and can thus be eradicated altogether or at least reduced to a minimum. As figures always attract attention, a comparison of the weight of several of the methods herein discussed may be interesting. These results must be approximate, because no two vessels are ever exactly alike in their equipment; but, in order that a fair comparison might be submitted, the writer has based these calculations upon a general type of equipment and computed the different proposals upon this type without considering specific changes.

Installation of cables encased throughout by conduits.....461,000 pounds.
Installation of mixed conduit and open wiring.....353,900 pounds.
Installation of lead-covered, steel-armored cables.....281,500 pounds.

This indicates a saving of 81 tons in favor of steel-armored, lead-covered cables over a full conduit installation; and a saving of 32 tons in favor of steel-armored, lead-covered cable over a mixed installation of open-wiring and conduit. This saving of weight by the use of steel-braided, lead-covered cables will be greatly increased as the manufacturers become more proficient and when deductions can be made from results gained in service.

PROPULSION BY MEANS OF ELECTRICAL COUPLING.

A lengthy discussion of this subject is not to be undertaken in this paper. The various methods proposed to-day have been collected in one volume by Mr. H. M. Hobart, and those interested would do well to consult this little book. At the end of this volume a description of Mr. W. L. R. Emmet's system is given, with developments up to the year 1911. In a paper presented by Mr. Emmet before The Franklin Institute this year he disclosed advances that are more than ever encouraging and more than ever indicative of the future. And as it is this future which this paper is dealing with more particularly, stress should be laid upon Mr. Emmet's improvements. Briefly, he has succeeded in designing a high-speed turbine with an efficiency of 73 per cent.; he has designed a motor which may be reversed at full speed and full load without the use of external resistance; and he has brought the water rate down to a penalized guarantee of 11.5 pounds per shaft horsepower in the application to the U. S. collier *Jupiter*.[4]

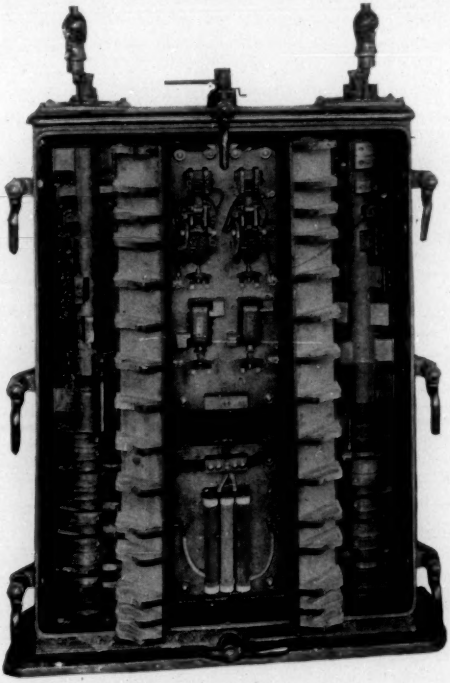
It is generally agreed to-day that for this purpose alternating current is better adapted than direct current. Therefore, the suggestion is here made that the war vessel of the future, or the real modern battleship, will be one in which the electrical equipment will assume the proportions of a good-sized central station;[5] and many of the problems encountered in this practice on shore will have a like value on board ship. One important way that this problem will differ Mr. Emmet has pointed out, and that is, that the load will be constant, so that the power re-

[4] Mr. Emmet advises that in a large battleship installation with 260 pounds steam pressure, 28 inches vacuum, and 50 degrees of superheat, the water rate per shaft horsepower would be less than 10 pounds.

It should be noted that in Mr. Emmet's proposed system of electric propulsion the main turbine speed varies with the desired speed of the ship, and could not, therefore, be used for a source of power for driving auxiliaries.

[5] Messrs. Donnelly and Orrok, in a paper presented before the Society of Naval Architects and Marine Engineers, November, 1912, proposed a central plant for the production of electricity, and the use of this power for propelling excursion steamers. They touched briefly on the important advantage of the utilization of this power when conditions would not permit the use of the vessel. When applied to a battleship these proposals assume a greater importance.

quirements will be established and the machinery designed for a flat rating. We will then have a central station in the vessel with a capacity from 26,000 to 30,000 kilowatts. This station will be designed and equipped with apparatus so that it may



Boat handling controller with cover removed, showing double drum, one for controlling the two motions, either rotating or hoisting, or boom-lifting or hoisting, as the case may be. Note compactness of design and method of securing water-tightness.

supply both the energy necessary to propel the vessel as well as that required for auxiliaries. It is believed that the equipment will be more economically and reliably handled by an alternating-current system, and the efficiency of the engineering greatly improved.

CONCLUSIONS.

The proposed use of alternating current on shipboard is not new. Mr. F. O. Blackwell read a paper before the Society of Naval Architects and Marine Engineers at a meeting held in New York City, November, 1902, in which he proposed the use of a 3-phase, 3-wire, 220-volt system and outlined its advantages over the 2-wire, 125-volt direct-current system. It is interesting now to note that he advised the use of turbo-generators instead of the then customary reciprocating engine for driving dynamos. For the last eight or nine years we have employed the turbine for this purpose.

In *The Journal of the Naval Institute*, No. 138, will be found an article by Lieut. S. N. Robinson, U. S. A., giving ample reasons for the employment of such a system on our modern war vessels; and in the February number of *The Journal of the American Society of Naval Engineers* appeared a detailed paper by Lieut. A. Norris comparing the advantages of a 230-volt alternating-current system with the present standard 125-volt direct-current system.

The possibility of electric propulsion and the increase in motor applications take us beyond these low potentials and away from the advantages of direct current. If satisfactory service is given by the use of 2200 volts alternating current for the propulsion of the vessel, there could be no reason forbidding its use elsewhere in the ship. At this potential direct current would react detrimentally on the hull structure and would not provide the flexibility inherent to alternating current. The ease with which alternating-current voltage may be reduced will restrict the distribution of high potential to those portions of the vessel where it may be cared for with safety. Concisely stated, alternating current affords the economical production of power in large quantities at high pressure, accompanied by a flexible system of distribution.

Peanut Butter. W. R. BEATTIE. (*Bureau of Plant Ind. Circular* 98.)—This is a brief account of the manufacture of peanut (earthnut) butter, a food product consisting of fresh roasted peanuts ground finely and flavored by adding salt. It is estimated that in 1911 approximately 1,000,000 bushels of the shelled nuts were used for the manufacture of peanut butter in the United States.

THE DEVELOPMENT OF THE TALKING MACHINE.*

BY

EMILE BERLINER,

Member of the Institute.

To receive the commendation of The Franklin Institute in recognition of endeavors relating to technical or scientific developments should in itself be ample reward for satisfying the higher aspirations of the engineer. Those in particular who appreciate the high standing of the Institute before the world and the eminence of the men that are its leaders and compose its committees will always be profoundly gratified when they are favored by the awards with which the Institute vouchsafes its good opinion. Needless, therefore, for me to assure you how grateful I am because it has been my good fortune to labor in promising fields and because I was able to win your expressions of approval.

Nor is it the first time that the Institute has invited me here to speak in this hall. It was twenty-five years last week that I gave here the first public exhibition of the gramophone and read a paper describing its then short history and its processes.

On that evening of May 16, 1888, I showed in this auditorium how a voice could be etched into metal, and, while the etching was being done, I rendered a programme of songs, recitations, and instrumental solos previously prepared which, crude as they were, presaged the possibilities of more perfect results for the future. These disk records, the first of their kind, were reproduced on a machine turned by hand, and all of them were originals. One duplicate was shown and reproduced, and this had been made by electrotyping an original sound etching in the same manner as an etched halftone is electrotyped. It was, however, easy to foresee the vast possibilities of the invention, and under the paragraph "Practical Applications" I ventured the following predictions:

* Presented at the stated meeting of the Institute, held Wednesday, May 21, 1913, when Mr. Berliner received the Institute's Elliott Cresson Medal, in recognition of his contributions to telephony and to the art of sound-reproduction.

A standard reproducing apparatus, simple in construction and easily manipulated, will, at a moderate selling price, be placed on the market.

Those having one may then buy an assortment of phonautograms, to be increased occasionally, comprising recitations, songs, chorus, and instrumental solos or orchestral pieces of every variety.

Prominent singers, speakers, or performers may derive an income from royalties on the sale of their phonautograms, and valuable plates may be printed and registered to protect against unauthorized publication.

Collections of phonautograms may become very valuable, and whole evenings will be spent at home going through a long list of interesting performances.

Languages can be taught by having a good elocutionist speak classical recitations and sell copies of his voice to students. In this department alone, and that of teaching elocution generally, an immense field is to be filled by the gramophone.

Addresses—congratulatory, political or otherwise—can be delivered by proxy so loudly that the audience will be almost as if conscious of the speaker's presence.

A singer unable to appear at a concert may send her voice and be represented as per programme, and conventions will listen to distant sympathizers, be they thousands of miles away.

On that evening the status of talking machines was as follows: The tinfoil phonograph of Edison had been known for ten years and was a scientific curiosity only, though of historic value. The wax cylinder phonograph or graphophone of Chichester Bell and Sumner Tainter had been invented, and its aim, as pronounced by its promoters, was to become a dictograph for private and business correspondence. Both machines represented a system of sound recording in which sound waves were either vertically indented, as in the Edison phonograph, or vertically engraved into a wax cylinder, as in the Bell-Tainter graphophone. In reproducing these records a feed screw was provided which turned either the cylinder past the needle or the reproducing sound-box past the cylinder.

The gramophone changed all this. Its record was made horizontally and parallel with the record surface, and by itself it formed the screw or spiral which propelled the reproducing sound-box, so that while the needle was vibrated it was at the same time pushed forward by the record groove, and, as the sound-box was mounted in such a manner that it was free to

follow this propelling movement, it made the reproducer adjust itself automatically to the record.

I pointed out at the time that the horizontal record of the gramophone was better capable of recording sound in its entirety, while in the vertical record of the phonograph-graphophone a certain distortion took place which became more pronounced the deeper the sound waves indented or engraved the record substance.

When I returned from this exhibition to Washington I set to work trying to develop a duplicating process which should enable me to make any number of records of the same selection in hard, wear-resisting material, like celluloid or hard rubber. The first successful duplicate so produced was made for me in the same year in celluloid by Mr. J. W. Hyatt, well known to you as one of the inventors of celluloid, and this duplicate is still in existence (now in the National Museum in Washington), being the first sound-record duplicate in hard material which was made by pressing a reverse of the original record into hard material while the latter was softened by heat, and then chilling it while still under pressure. This process is at the bottom of the present industry of making many millions of sound-record copies annually.

The trouble I found with celluloid was that it was not quite hard enough for the gramophone system, and I therefore turned my attention to hard rubber. After several years of experimenting, trying to make accurate electrotyped reverses or matrices from original zinc records, so that the very surface, even to its microscopic details, should be copied, I finally succeeded and, with the help of a rubber company in the Middle West, to make large numbers of accurate copies from a matrix, and soon afterward I launched the disk talking machine on the market.

By 1895 the invention was so far perfected that it began to gain many admirers by its simplicity and ease of manipulation. But it soon developed that many rubber records were imperfectly pressed and showed flat places, and the rubber company was unable to correct this part of its work and furnish a reliable output.

In this emergency I remembered an attempt made by the Bell Telephone Company in 1879, while I had charge of its laboratory, to substitute a shellac composition for the hard

rubber of which its hand telephones were made, and I got in touch with a factory that made electrical fixtures of such composition. I gave them a nickel-plated copper matrix of a record, and the first copies they pressed from this matrix in shellac composition showed remarkable uniformity, and, moreover, because the material was harder than hard rubber, the reproduced sound was louder and more crisp. These composition duplicates proved at once a great success, and ever since shellac composition has been used for making disk records, although recently attempts have been made to employ for them a substance like bakelite.

As early as 1887 I had tried to make records by pressing a matrix into sealing wax, and it is interesting to realize that these modern composition disk records are in reality seals of the human voice, because the substance they are made of is a modified sealing wax, both containing shellac as a basic substance. Few people have a conception of the untiring efforts which have been made year after year, and still continue, in order to obtain a composition which will answer all the requirements necessary for resisting the wear of the needle or prevent the latter from being ground blunt too fast. If the material is too hard and gritty it will wear the point of the needle, so that before the end of the record is reached the reproduction becomes weak and blurred. If the material is too soft the record groove will quickly wear rough and the record reproduction become scratchy. Shellac is much adulterated, and the mineral and fibrous substances which are added require careful selection, and this whole department is in the hands of experts who do nothing else all the year around but test the substances and the mixing processes which are employed for producing record material.

Of recent years Mr. Joseph Sanders, of Washington, D. C., has perfected a record disk having a solid fibrous core which is faced on both sides with a very thin layer of shellac composition of a superior quality. Records pressed in such disks are remarkably smooth, and withstand climatic changes better than the others, so that they may be sent to the tropics without danger of being affected by the combined heat and moisture which abounds in those parts of the world. Moreover, these disks are light in weight and have sufficient flexibility to successfully withstand careless handling and breakage resulting therefrom.

After the hand-driven gramophone had been on the market for a few years the company which had been organized for exploiting the invention secured the co-operation of Mr. Eldridge R. Johnson, now the president of the Victor Talking Machine Company. An able mechanician and of shrewd technical perception, Mr. Johnson succeeded in developing a motor-driven reproducing machine which ran with great regularity of speed, was readily adjustable, and, last but not least, ran silently so as not to disturb the sounds of the record by its own noise. Such a motor machine had been made by a New York clockmaker as far back as 1891, but had not been quite noiseless at that time. Mr. Johnson also took note of the fact that the patents of Bell and Tainter covering the method of cutting a sound record in wax were approaching their final term of legal existence. He decided to take advantage of this circumstance and applied himself to the abandoning of the difficult etching process and of combining the much easier wax-cutting technique of the graphophone with the gramophone method of horizontal recording. He, of course, adhered to the automatic reproducing, to the disk form of record, and to the method of duplicating disks by impressing an electrotype reverse or matrix into shellac composition under heat and pressure.

We strike here an experience parallel to that which occurred in the early development of the telephone when two independent systems—the magneto transmitter and reproducer and the loose-contact transmitter and reproducer—were combined to form a system superior to either alone, when the loose contact was finally used as a transmitter and the magneto telephone as the receiver for telephonic intercommunication, the system which has been in use ever since.

In a similar manner Mr. Johnson took from the graphophone the recording in wax and added it to what the gramophone already had, and thereby produced the modern gramophone, also known as the Victor talking machine, Disk Graphophone, Columbia Phonograph, and other trade names.

And the machine which hitherto had confined itself to popular musical talents, to low comedy, simple songs, cornet and clarinet solos, and to military music, rapidly improved to such a degree that it began to appeal to grand opera stars, to the great masters of the piano, to the wizards of the violin, to

symphony orchestras, to virtuosos on every kind of musical instrument, and to celebrated actors and elocutionists. The gramophone repertoire expanded to comprise the whole gamut of audible phenomena, and musical reproductions in particular became so startlingly perfect that big hotels and restaurants were able to have their orchestras accompany the great singers of the day as they appeared by proxy out of the horn of the talking machine.

The predictions made before this Institute in 1888 were being fulfilled even to the application of the gramophone to national politics. Last year the speeches of the three presidential candidates were heard and reheard all over this country, and the recognition of the individual voices—something I had noticed in the very first gramophone records—was one of the notable characteristics of these speeches. The speakers were present in all but their bodies: the proxies were complete.

And down in extensive fire-proof vaults, built by the big companies here and in Europe and securely closed to all but a few trusted employees, are stored away the copper or steel matrices, the indestructible and precious legacies which the masters of song and performance are leaving to future generations. Their immortality is secure because the very air pulses which smote the ears and brains of their own generation are already being resurrected above the graves of those who have died.

What had in the meantime become of the cylinder machines? The graphophone or wax cylinder phonograph, true to its original programme, had developed into a most serviceable dictograph, and it is astonishing how much time and trouble is saved by such a machine to the business manager, to the press reporter and to the chief of office. Instead of calling for the stenographer just when the latter is perhaps busy transcribing from her notes on the typewriter, the manager takes one wax cylinder after another and dictates his letters or orders to the lifeless machine. He may do so in his leisure moments, immediately as a thought strikes him, and when the rack of wax cylinders has been loaded with his dictation or orders, he rings for a boy, who distributes the cylinders among the typewriters. These in turn place the cylinders on reproducing machines and with ear tubes over their heads and with nimble fingers on the

keys they transcribe from the talking record, now stopping to repeat a sentence, now taking notes of special orders with which the manager has interrupted his letter dictations. No time is lost in waiting; the strenuous life has permeated from the corporation manager to the most distant workers of his will, and the high speed of modern machinefy has a counterpart in those wonderful combinations of money and brains which grind out twentieth century enterprise in the steady flow of a rushing stream and as a continuous performance.

Thus does modern technical science in all its branches fill the pressing demands of an eager humanity even to overflowing. But a hand is raised in protest, and out from a misty past there looms up an ancient landmark of human history, an achievement of an earlier civilization. It is the Day of Rest, when tired brains turn to the woodland and the mountain stream, to green fields and meadows, and to the low song of birds, the chirping of crickets, and to the call of the whip-poor-wills, who decline to perform for talking machines and who, like some other ideals that appeal to the romantic within us, must be pursued before they will yield to us the rewards of their charms. Machines may give us talk and melody, light and comfort, speed, and even flight, but they will never give us life's poetry. And it is well that it be so.

The companies making cylinder machines soon began to observe that wax cylinders also contained possibilities as means of amusements, and they set to work invading this apparently profitable field of application.

Their principal problem consisted in finding a proper process for duplicating from the original cylinder record. The best method appeared to be that of the gramophone, namely, make an electrolytic negative or cylinder matrix from the original record and use this as a mould for casting duplicate cylinders. Unfortunately, however, cylinder records do not lend themselves readily to such a process. To deposit metal on the wax cylinder was easy, and the producing of a good negative or mould appeared to be a very simple matter, because the wax record was simply melted out of the copper shell, leaving on the inside a reverse of the sound waves. But, having produced this mould and pouring into it a cylinder of copy wax, it was difficult, and at first impossible, to separate the copy and get it out of the mould.

So for a time they abandoned this method and developed a mechanical duplicating machine in which, by means of a carefully-mounted lever, having a tracing point on one end and a cutting point on the other, the record was transcribed from the original cylinder upon duplicate blank cylinders, and this system was used commercially for a number of years with a certain degree of success.

However, the laboratories of the several cylinder factories continued experimenting with the electrolytic method, and finally they produced a wax for casting the duplicate cylinders, which on the application of cold would sufficiently contract inside the copper cylinder as to permit the duplicate to be slipped out. This obstacle having been overcome, it was then found, however, that the matrix or mould did not represent the original record in all its perfection, but had lost in quality and surface because of the brushing with graphite necessary for making the original wax surface electrically conductive.

This difficulty was finally overcome by Mr. Edison through the development of a so-called process of gold moulding. This consisted in passing a high-tension current through a vacuum in which the wax cylinder record formed one terminal and a gold anode the other. Infinitesimal particles of gold are thereby transferred upon the surface of the wax record until it is entirely covered, and it is then placed in an ordinary copper bath and a good thickness of copper deposited over the gold, after which the wax is melted out.

Such a mould is a perfect reverse of the original record, and it enabled the Edison Company to place upon the market complete assortments of cylinder records in competition with the gramophone or Victor disk records.

While I cannot admit that such phonograph-graphophone records ever came up to the expectations of the most critical, they satisfied thousands of people who appreciated the fact that, in reproducing these records of a softer material, they were not obliged, as in the gramophone, to change the needle with every record, since wax or even celluloid does not wear a needle as rubber or shellac composition does.

Of the many minds working on talking machines, some presently turned to the very natural idea of producing records of the phonograph up-and-down system in disk form. This was

not new, but had never been developed. The advantages were obvious, because disks can be duplicated easier than cylinders and can be made in hard materials which could be more easily handled and occupied less space.

The first commercial disks with phonograph up-and-down recording were placed on the market by the firm of Pathé Frères, the well-known cinematograph and film manufacturers in France. The method employed by this firm, however, was not the simple one of recording sound into wax disks and then duplicate by the same method as employed in the gramophone. Pathé, owing to some technical difficulties in direct recording, first recorded on a very large cylinder of about 12 inches diameter, after which they mechanically transferred this record to a wax disk by means of a system of levers, and from this disk they developed a matrix in the usual manner.

Recently, however, the Edison Company has been recording phono-vertical records directly into wax disks and then following the gramophone method of duplication. We have, therefore, on the market to-day disk records not only of the gramophone type where the sound waves are of even depth and vary horizontally, but also those of the phonograph-graphophone system in which the sound waves are represented by corresponding variations only in the depth of the record groove.

On the theory developed by me twenty-five years ago, that a vertical record must distort the original sound in proportion to the depth of indentation or cutting, we have then arrived at a point where a phonograph-graphophone or vertical record in disk form may closely approach the perfection of a horizontal or gramophone record, provided the phonograph record is cut extremely shallow. In this condition, however, the record groove cannot readily guide or propel the stylus, and it requires a feed screw for propelling either the disk or the sound-box. It has been tried to first cut a plain spiral groove, deep enough for propelling the stylus, and then superimpose at the bottom of this groove a phonograph-graphophone record, but this method has shown sufficient difficulties for preventing its introduction up to the present time. The gramophone type of talking machines still prevails, and every year brings it closer to a fidelity in recording and duplicating which should satisfy the most exacting critics. The celebrated stars of grand opera would hardly

entrust the keeping of their voices to any talking machine except they felt that the records represented their art in a satisfactory manner.

And such is the status of the talking machine at the present time. Considered critically, the principal further advances should be the making of disk records in a material of the character of glass or hardened steel in which they would retain a polished surface indefinitely and which, on account of great hardness, would prevent the slightest loss in the most delicate vibrations recorded on the original disk. Bakelite would appear to be a promising substance, but it needs adaptation to requirements which escape the chance observer.

In the mere mechanical part of talking machines an electrically-driven reproducing disk machine generally introduced would undoubtedly commend itself to a discerning public. Such an electrification of disk talking machines, by relieving the present hand-organ energy, would make for an increase in æsthetic enjoyment such as the promoters of talking machines are ever anxious to secure for their products.

Before closing this paper mention should be made of that very ingenious device, the telegraphone, developed by Mr. Poulson, of Denmark. In this instrument telephone sound waves are made to record themselves as localized magnetic fields of different lengths and intensities in a steel wire, on a steel tape, or as a spiral record on a steel disk. In the reproduction these magnetic fields, by passing in touch with a small electromagnet, cause electric undulation corresponding to the original sound waves in the helix of this magnet. The circuit of the helix includes a telephone receiver, which then emits the sounds originally spoken into the telephone transmitter.

Beautiful as this system appears to be, it suffers from the inherent fault that you cannot confine a localized magnetic field representing a sound wave as you can define a mechanical record of the same. As a consequence articulation is impaired because the magnetic halo of one wave superposes the halo of the next, and this is fatal to those delicate overtones which form the essential characteristics of most consonants. To remedy this the linear speed of the record was increased, but it then became cumbersome on account of too great length, and it still showed

losses in articulation because of the several electromagnetic transformations which are embodied in this system.

Magnetic fields were long ago localized in the well-known experiment of writing with a magnet on a piece of steel and then strewing iron filings over it, when the writing appeared as lines of iron filings which stuck to the magnetic tracings. The first who proposed to apply this principle to the recording of sound by fixing telephone undulations on a steel ribbon or wire and cause such a magnetic record to induce telephonic undulations by magneto-electric impulses and reproduce the original sound was Mr. Oberlin Smith, now of Bridgeton, N. J., who published this idea in a prominent electrical journal some years before the advent of the telegraphone. Mr. Smith himself, however, did not carry the plan into successful execution, and I do not know whether Mr. Poulson knew of the Smith publication when he took up and successfully completed the telegraphone.

The instrument remains to-day a beautiful demonstration of electrical and magnetic phenomena as applied to the transmission, recording, and reproduction of speech, but its ultimate development into as perfect and practical an apparatus as the mechanical talking machine appears to be is precluded by the existing conditions.

We have in one of our offices a photograph which one of our travelling salesmen brought back from a business trip to the trade centres in the wilds of Canada. It shows a giant lumberman reposing placidly on a rough bench in front of his crude log cabin. Nothing but forest and mountains surround him. His axe and his shotgun lean against the cabin within easy reach, he is smoking his pipe, and his faithful dog crouches at his feet. His nearest neighbors are miles away, and in days gone by the solitude of his existence would have been but rarely relieved by diversions or pleasures, and then only by occasional visits to the centres of supplies, where barrooms, gambling dens, and low dance halls satisfied his yearning for a change from his laborious daily life.

But now there stands in front of him a rough dry-goods box, and on it he has placed an old-time horn gramophone and a stack of disk records. The concert halls, the vaudeville and

opera houses of the world are represented in that pile; English statesmen and American Presidents may talk to him as if face to face, and he can entertain his occasional visitors with the same choice selections that are heard in the drawing-rooms of mansions occupied by the favored few, be they of the capitals and metropoles in the far away.

We framed that picture and wrote under it the words "In Touch With Civilization."

Close-plated Platinum Utensils. ANON. (*Brass World*, ix, 3, 84.)—The high cost of platinum has led to many experiments to produce cheaper platinum vessels. Byron E. Eldred, of Bronxville, N. Y., has taken out various patents for close-plated platinum dishes, crucibles, and other apparatus used in the chemical laboratory. The platinum is welded to a base of steel or nickel and then rolled into a sheet, which is then spun into the desired shape. The surface is thus coated with platinum, but the edges are exposed base metal. To cover these up, platinum is fused on the edges, and thus an article is obtained completely coated with platinum but at a much less cost than a solid platinum vessel. The interior of steel or nickel can be made of sufficient thickness to make the articles quite stiff and rigid if desired.

Prevention of Leakage in Steam Metal Valve Castings. ANON. (*Brass World*, ix, 3, 79.)—Valves are tested after finishing at various pressures, according to the work for which they are intended, by hydraulic pressure, air, or steam, to ascertain if there is any leakage. Brasses and bronzes are equally liable to leak. Leakage is not caused by any lack of tensile strength, but by the presence of dross, by blow-holes or other imperfections in the metal, that is to say, it is a matter of foundry practice. The causes of leakage are: (1) pouring the metal too cold; (2) too short gate; (3) oxidation of the metal in melting; (4) walls of valve too thin; (5) aluminum in the metal; (6) sulphurizing of the metal during melting; (7) core-box or pattern badly made, so that the casting is thick on one side and thin on the other; (8) wrong metal mixture; (9) gated in wrong place; (10) use of large quantity of phosphorus as a deoxidizer; (11) too little tin in the mixture; and (12) sharp corners on the pattern. The presence of dross (oxide) in the metal is the cause of nearly all leakages.

THE IMAGINATIVE FACULTY IN ENGINEERING.*

BY

ISHAM RANDOLPH, D.Eng.,

Member of the Institute.

"We had visions, oh! they were as grand
As ever floated out of fancy land,"

are words sung by a poet of our own land to the ears of a few who knew, honored, and loved the singer. He sang of "The Lost Cause" with a beauty and a pathos that touched the hearts of all who mourned for the men who followed that "conquered banner" along the path that led "to glory and the grave."

The sculptor beholds in blocks of marble forms that are hid from his fellow-men, who see only a mass of stubborn stone. The explorers of Olympia have resurrected from the detritus which buried them treasures of Grecian art wrought from the marbles by Phidias, Praxiteles, and others whose chisels made Greece beautiful and themselves famous. Within our own time one of our own race and nation saw in a marble block an imprisoned form and day by day, with mallet and chisel, he toiled to liberate the loveliness of face, torso, and limb that duller eyes could not see, but which the opaque covering could not hide from him. The encasing stone must be removed carefully, skilfully, gently, that the fair brow might not be scarred nor the delicate outlines of the face, form, or limb be marred. Little by little the revelation which, from the first, was so clear to the sculptor came to his dull-eyed fellows, and at last the Greek Slave came forth in all of her womanly beauty to delight the human vision until she, too, shall some day be buried, like the wonderful creations of Praxiteles, in some overwhelming convulsion of Nature.

It is not, however, of the poet's inspired imaginings nor of the revelations of the sculptor's art that I am to speak, but of

* Presented at the stated meeting of the Institute held Wednesday, May 21, 1913, when Dr. Randolph received the Institute's Elliott Cresson Medal, in recognition of his achievements in civil engineering.

the "Imaginative Faculty in Engineering," for the engineer, no less than the sculptor, sees things that are hid from other eyes than his.

What has not God revealed to the sons of men when He has drawn aside the veil and let the thing that is to be cast its reflection upon the mirror of imagination? Away back in the ages when the children of Israel were wandering in the Wilderness it was disclosed to their Moses that a tabernacle must be created as the centre to which the worshippers of the Most High God must gravitate, and to him was revealed the form, the fashion, and the adornment of this "temple made with hands," and the final command, after all had been shown to his mental vision, was: "And look that thou make them after the pattern that was shown thee in the mount" (Exodus xxx: 40).

A man's first conception of anything which ought to be created is his vision, the revelation which impresses itself upon his imagination with a reality that enables him to reveal it to others, either by word-painting or by graphic delineation which, after taking form, must be given substance. Giving the substance to the form involves knowledge, knowledge of materials, knowledge of the strength of materials, the ability to determine dimensions which must be used to give sustaining power to the substance which has taken the form revealed to the imagination.

The vision does not always come complete in its revelation. First it may be dim, "seen through a glass darkly"; partially-obscuring mists hide all but a suggestive glimpse of the thing that is to be, but that suggestion is grasped by the imaginative faculty, and the eye of the mind gazes earnestly, waiting for the passing of the mist and the perfect unveiling of the vision. How many of earth's monuments which now stand to the honor of the engineer and render useful service to mankind had their genesis in imagination! Take some mighty suspension bridge whose graceful catenary is not distorted by loads which would bend a Titan's back, and, as you gaze upon it, think how it came to pass. It supplies a need, a great need; multitudes felt the need, but the way to supply it was not given to the multitude. One among them all saw the vision. He saw the great river flowing by; he felt that the bank on which he stood should be joined to the farther shore; but how? His imaginative faculty began to work. Here and over yonder he would dig down into

the soil until he reached a stable base; in the pits so sunk he would lay firm foundations upon which he would rear towers, high and strong. Inland from these towers he would plant massive anchors of masonry; from the anchor on the hither shore to the anchor on the nether shore he would pass cables over his high towers, cables that sagged between the towers, and from these, by rods, graduated in length, he would suspend beams, and on these beams he would lay his flooring: all of this was pictured by his imagination. From that picture, as he saw it, he made a material transference which could be seen by his fellow-man. He called his fellow-man, skilled in the knowledge of engineering science, to his aid, and form and proportion were developed and the necessary strength for every part was computed. The cost was figured out, and all that could be known in advance about the bridge that was to be was laid before the rulers of the people. The plan was adopted; deep down to an enduring base the foundations were carried by men whose strength and toil rear all of earth's structures, be they perishable or enduring. Those skilled among them in the arts of stereotomy builded the masonry strong and high. In the works where ore, dug from the mines, is melted and fused by coal dug from other mines, the members, of mighty section and prodigious strength, are forged and fabricated. In other works, the wires that in union will make the strength of the great cables that shall stretch across the stream are being drawn. Trees of centuries' growth, felled in far-off forests, are being sawn and fashioned for their place in the work, and when all is ready the multitudinous parts are assembled, the cables are made fast to their anchorages and lifted to their saddles on the tops of the towers by machines which—like the work which they are set to aid in creating—had their beginning in the imagination of man. By and by, all is accomplished, and two tides of humanity ebb and flow across the mighty bridge which had its genesis in the imagination of a man.

No river sways such power for good to the whole land if made amenable to human control, and no river in the land is so terribly devasting in its unbridled power, as is the Mississippi. Against its encroachments men have raised barriers, broad and strong, only to have them undermined and engulfed by the onsweeping waters.

This river, for scores of miles before it pours its sweet waters into the brine of the Gulf, is wide and many fathoms deep; but for uncounted centuries it has been transporting soils, filched from its banks, and depositing them at its mouth; building land out into the Gulf, and finally crossing barriers of its own construction, not by one channel, but by many. No one of these channels was deep enough to permit ocean-going vessels of the larger class to enter the deep, wide water that came down from the north and then flowed by shallower ways over the barrier and out to sea, and so commerce upon the river was only for river craft, and cities which were waiting for their upbuilding for the coming of the world's commerce had to sit beside their incipient docks and wait. Governmental forces had worked and were working ineffectually upon the problem of opening up "the passes." About the year 1875 a man with a vision came to the Government with a plan to secure deep navigation across the bars that closed the mouth of the river. The engineers of the Government were told of the vision, but the dreamer could not impress them with his faith. They perhaps had not seen, as he had, what had been done with a river in the old land. The Government would not take any risk to open the Mississippi, but Eads—the man with engineering imagination—so impressed his vision upon men of means that they guaranteed his proposal to the Government, agreeing to put up all the money and take all the risk, provided the Government would reimburse them when success was demonstrated and deep-draught vessels could enter and leave the Mississippi without hindrance. This man saw in his vision two lines of jetties constructed of willow mattresses weighted with stone, laid parallel to each other and a thousand feet apart. These, in his mind's eye, grew in height and length until they stretched from deep water up stream to deep water in the Gulf. He saw the waters as they flowed down to this contracted channel pile up until they attained a head sufficient to give them the necessary velocity to carry through the reduced cross section the volume which had flowed sluggishly through the wider way. He saw the velocity impart erosive energy to the waters which impinged upon the sand of the bottom of this new channel; each eroding drop of water picking up its grain of sand and carrying it along until, emerging into the unlimited area of the Gulf, it lost its energy and dropped its load. Thus myriad

drops of water carried myriad grains of sand, and every grain removed tended to deepen the channel between the jetties. This he saw, and thus did the waters labor until they had dug for themselves a way out to the Gulf, through which they might flow unvexed, and when that work was accomplished the way was open for the "toilers of the sea" in their deep-laden craft to pass to and fro between the "Crescent City" and the sea ports of the world. The imagination wrought first and the physical results confirmed its visions.

Yonder where the waters of Niagara make their fearful leap over the edge of the escarpment and then rush madly down the gorge to the whirlpool and beyond the "imaginative faculty in engineering" has left its impress, and great works bear witness to the fact that there it has wrought mightily. Back of that awful sheet of falling water there is a pathway, forever wet with the off-flung spray; on one side is the hard wall of the escarpment, on the other the wall of green, translucent waters, the dim twilight effect made awesome by the roar of the torrent wall as it drops into the abyss—a wall forever falling but never broken. A man trod this dangerous path and he heeded not the roar, nor the mist, nor the death that might claim him should he make a false step on that slippery footing. No! he saw a vision; the imaginative faculty in engineering was aroused. His eye pierced the face of the escarpment, and he saw a tunnel open up through the rock beneath the river. His tunnel went straight to a spot in the roaring, seething waters some thousands of feet from where he stood, and there he saw a deep, long slit in the rock, rising from the up-stream end of his tunnel to a stately building. In the building there were generators carried on top of vertical shafts which were caused to rotate by turbines at their lower ends down in the bottom of that long, deep slit in the rock. All this and more the "imaginative faculty in engineering" revealed to that engineer, and the engineer made it plain to the men with money that the sublimation of his vision would make their money earn more of its kind, and to-day you may look upon the completed work of the Electrical Development Company and know that it is there because of the imaginative faculty in engineering.

Another engineer explores the canyon of a river; here it flows between granite walls that tower on either side above its rushing

waters. The walls here are not far apart, and an idea, a vision, comes to the engineer. That river at times is a torrent; the rains have descended and the floods have come and the river rushes on, a destructive agency, leaving a land behind perishing of thirst. The engineer asks himself, "To what purpose is this waste?" And again, "Why should not this waste be prevented?" And the answer comes, "It can be, and you can do it." Then he sees the way. There is the pass. He will hold the pass against the oncoming waters. The imaginative faculty is at work and shows him that deep down beneath the stream there are footings "sure and steadfast" on which he can found a dam; this dam he can anchor into the granite banks of the stream. That was a revelation; to-day there is a reality. The Arrow Rock Dam rises 351 feet above its base and the waters rush against it; they stop and swell and press, but the dam is stronger than the pressure. The floods have lost their freedom, the waste of waters has been stopped after untold ages, and to-day they are garnered and sent to make gardens in the desert; and, like Samson of old, they must grind in their prison-house and give off power which will do man's work and light man's dwellings. The voice that spake to Moses speaks to the engineer to-day: "And look that thou make them after the pattern that was shown thee in the mount."

Separation of Radio-active Substances from Thorium. F. GLASER. (*Chem. Zeit.*, xxxvii, 477.)—Monazite sand is mixed with twice its weight of concentrated sulphuric acid and heated to 25° C. for five hours with constant stirring. When cold the mass is poured into 20 volumes of water and filtered after 24 hours. By diluting this mixture, or by adding magnesia to it, a precipitate of thorium phosphate is obtained. A better method is to dilute till the free sulphuric acid is reduced to 2 to 3 per cent. and then boil the solution, which produces a voluminous gelatinous precipitate of thorium phosphate and its radio-active derivatives. This precipitate contains thorium Y, which may possibly be identical with thorium X. To separate the thorium Y, the moist precipitate is treated with dilute sulphuric acid, or else dried, heated with concentrated acid, and poured into water. The thorium is dissolved as sulphate, leaving somewhat impure thorium Y undissolved. The half period is about four days. Thorium preparations which yielded thorium X on treatment with ammonia did not yield thorium Y when treated by this method.

A MAINTENANCE-OF-WAY DEPARTMENT RAILROAD TESTING PLANT.*

BY

B. B. MILNER,

Member of the Institute.

SOME time ago the writer, whose experience has been chiefly with railway motive power, was asked to assist a maintenance-of-way engineer in the investigation of a problem which involved a study of track design and the stresses imposed upon its various members.

Consultation with several men of recognized experience and authority, as well as an investigation of all experimental work performed in this connection, and a search through the literature of the subject, revealed the fact that dependable data upon which to base definite conclusions upon various points raised were lacking.

This same revelation was made by Mr. O. E. Selby, Bridge Engineer of the Cleveland, Cincinnati, Chicago & St. Louis Railway, in writing an admirable paper, entitled "A Study of the Stresses Existing in Track Superstructure and Rational Design Based Thereon," which was published in Bulletin No. 80, American Railway Engineering and Maintenance-of-Way Association, October, 1906. This paper contained several paragraphs elaborating upon the statement that "railroad track has grown in strength as heavier loads have made increased strength necessary, but such growth has been entirely along empirical lines, and not one single detail of track superstructure bears marks of engineering design."

Mr. Selby, after careful consideration of such factors as rail loading and stress therein, tie bending, bearing of tie upon the ballast, depth of ballast and its bearing upon the subgrade, developed the track design shown in Fig. 1. The sizes on the drawing are for 60,000-pound axle loads. The principal sizes for 50,000-pound loads, using various weights of rail, are given in Table I.

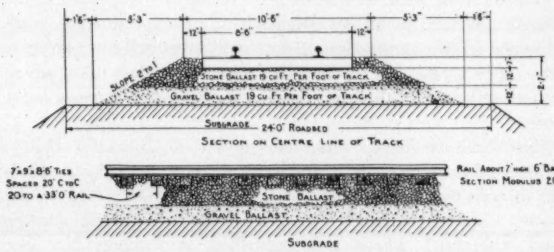
* Communicated by the author.

TABLE I.

Rail.....	80 pounds	90 pounds	100 pounds	Rail with Sec. Mod. 20
Axle load.....	50,000	50,000	50,000	60,000
Size of ties.....	7″ x 8″ x 8½″	7″ x 8″ x 8½″	7″ x 8″ x 8½′	7″ x 9″ x 8½′
Spacing of ties....	16½″	18″	20″	20″
No. of ties 33-foot rail.....	24	22	20	20
Depth of ballast...	14″ stone	16″ stone	18″ stone	12″ stone 12″ gravel
Width of roadbed..	21′	21′	22′	24′

From this table it is at once seen that the number of ties per 33-foot rail, as well as the depth of ballast, is much greater than that found in standard track to-day, and, since the figures

FIG. 1.



Track superstructure for 60,000 lb. axle loads.

in the table are the result of a careful consideration of the strength of the materials involved, it is not surprising that the question of strengthening our present standard tracks is becoming such a live one, especially with our heavier trunk lines.

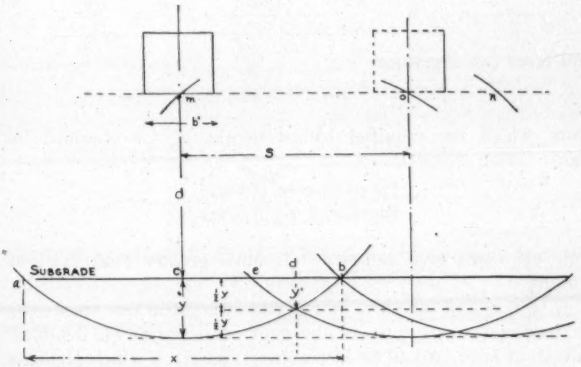
The depth of ballast, computed by Mr. Selby, was obtained from formulæ for the thickness of ballast necessary to produce equal distribution of axle loads on the surface of subgrade beneath the ballast, for which Mr. Thomas H. Johnson, Consulting Engineer of the Pennsylvania Lines West of Pittsburgh, was responsible. Mr. Johnson deduced these formulæ after studying a report, made by Railroad Director Schubert, of Berlin, in 1899, of observations extending over a period of over three years, on the action of ties actually in track. This report was translated and published by Mr. W. C. Cushing, Chief

Engineer, Maintenance-of-Way, Pennsylvania Lines, and appeared in Bulletin No. 76 of the American Engineering and Maintenance-of-Way Association, June, 1906.

In Mr. Johnson's formulæ the two following premises are made:

1. "That the width of distribution of the load is equal, for stone ballast, to the width of the tie plus the depth of the ballast, and, for gravel ballast, to the width of the tie plus half the depth of the ballast."

FIG. 2.



From Fig. 2 this premise may algebraically be expressed thus:

For gravel, $x = b' + \frac{1}{2} d'$ ..... (1)

For stone, $x = b' + d'$ ..... (2)

where x is the width of ballast pyramid carrying the load.

2. "That the intensities of pressure within that width are proportional to ordinates to an arc of a circle whose radius and chord are each equal to the width of distribution of the load."

The deduction of the formulæ is as follows:

If the circular arcs be considered as approximate parabolas, the intensities of pressure may be assumed to be proportional to

the ordinates of the curves. The area of the parabolic segment $= \frac{2}{3}xy$, hence the mean ordinate $= \frac{2}{3}y$, or the mean pressure $= \frac{2}{3}$ the maximum.

The pressure at b is 0, hence, to obtain an approximately uniform distribution of pressure over the surface of the subgrade, the tie-spacing S must be such that the curves overlap and have a common ordinate y' equal to $\frac{1}{2}y$. This will obtain when $db = \frac{1}{4}\ cb$; $eb = \frac{1}{4}\ ab$ or $mo = \frac{3}{4}\ mn$.

Hence, the tie-spacing $S = \frac{3}{4}x$.

Therefore, from (1), for gravel,

$$S = \tfrac{3}{4}\,(b' + \tfrac{1}{2}\,d')$$

and from (2), for stone,

$$S = \tfrac{3}{4}\,(b' + d')$$

from which the required ballast depths d' are obtained by transposition:

$$\text{For gravel, } d' = \tfrac{8}{3}\,(S - \tfrac{3}{4}\,b')$$
$$\text{For stone, } d' = \tfrac{4}{3}\,(S - \tfrac{3}{4}\,b')$$

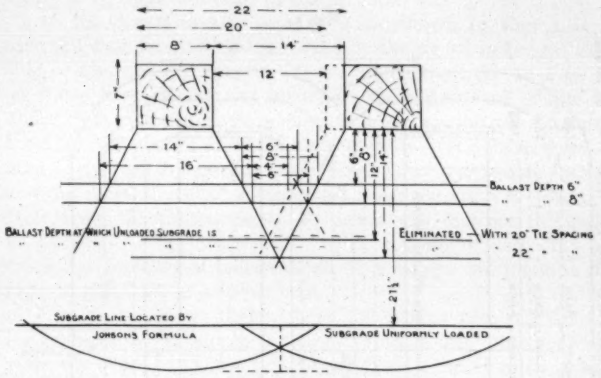
both of which give values of d' much greater than exist in practice.

The question whether, in order to strengthen our tracks for the increased loads imposed, the number of ties or the depth of ballast, or both, should be increased, is one upon which opinions vary widely among those concerned. The following is here presented in this connection:

Fig. 3 shows a diagrammatic section of the ordinary standard main line track, in which 7-inch by 8-inch ties are spaced 22 inches apart, or 18 per 33-foot rail, and laid upon 6 inches of ballast. The slopes of the ballast pyramids, transmitting the load from bottom of tie to subgrade, are determined in accordance with Mr. Johnson's premises for the distribution of pressure at the bottom of stone ballast. It will be noted that the width of the base of the ballast pyramid under each tie is 14 inches and the width of the strip of subgrade unloaded and lying between adjacent ties is 8 inches. As shown by Director Schubert's experiments, and in line with the experience of all trackmen, the subgrade line, originally straight, will be disturbed, as AB in

Fig. 4, the amount of disturbance being proportional to the weakness of the subgrade and to the ratio of the area of subgrade

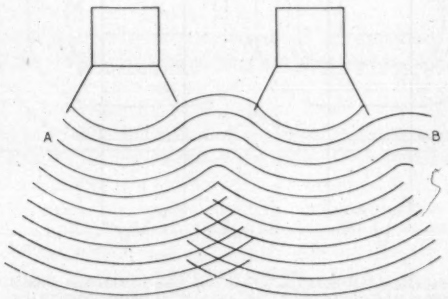
FIG. 3.



Section of Standard main line track.

between the loaded ballast pyramids and that of subgrade beneath the ballast through which the load is transmitted.

FIG. 4.

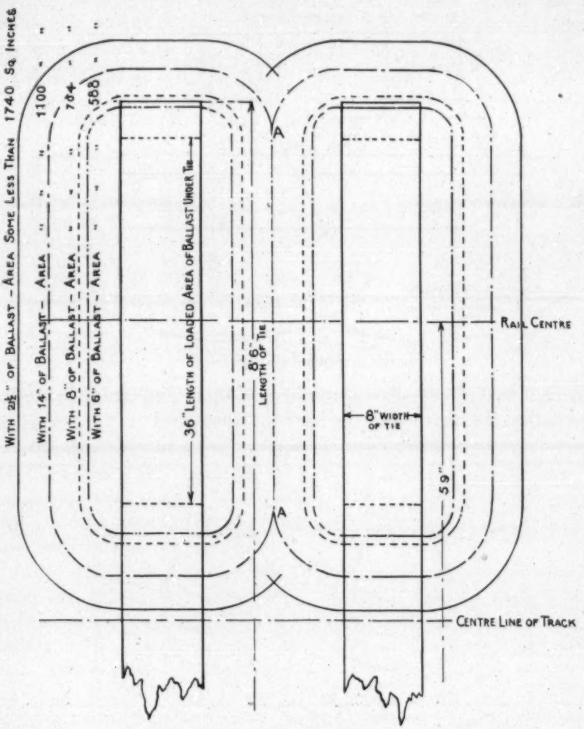


Sketch showing distortion of ballast under loaded ties.

By changing the tie-spacing to 20 inches, or 20 per 33-foot rail, as shown dotted in Fig. 3, the ratio of loaded to unloaded

width of subgrade at the 6-inch depth of ballast becomes 14/6 instead of 14/8, an increase of 33⅓ per cent. The subgrade is more nearly confined, a condition which, of course, materially

FIG. 5.


WITH 25" OF BALLAST - AREA SOME LESS THAN 1740 SQ INCHES
WITH 14" OF BALLAST - AREA 1100 "
WITH 8" OF BALLAST - AREA 704 "
WITH 6" OF BALLAST - AREA 588 "
36" LENGTH OF LOADED AREA OF BALLAST UNDER TIE
8'6" LENGTH OF TIE
8" WIDTH OF TIE
59"
A
A
RAIL CENTRE
CENTRE LINE OF TRACK

Sketch of track plan.
7" x 8" x 8' 6" ties spaced; 22" or 18" per 33' rail. Showing outlines and areas of loaded sections of subgrade with 6", 8", 14" and 21½" of ballast under the ties.

increases its carrying capacity. Maintaining the 22-inch tie-spacing and increasing the depth of ballast from 6 inches to 8 inches changes the ratio of loaded to unloaded width of sub-

grade from 14/8 to 16/6, an increase of approximately 52½ per cent.; while the combination of the decreased tie-spacing and increased ballast depth increases the original ratio from 14/8 to 16/4, or approximately 128.6 per cent.

In the diagrammatic plan of track shown in Fig. 5 it is assumed that the rail load is spread by the tie 18 inches on each side of the rail centres, or, for an 8-inch tie, over an area of 36 times 8 = 288 square inches of the lower face of the tie under each rail, and over somewhat less than the 36 + 6 times 8 + 6, or 588 square inches of the subgrade. The corresponding area of unloaded subgrade is 42 times 8, or 336 square inches, and the ratio of loaded to unloaded subgrade areas is 588/336. Decreasing the tie-spacing to 20 inches will increase this ratio to 558/252, or 33⅓ per cent., while combining with this decrease, an increase of ballast depth of 2 inches, will increase the ratio to 588/168, or 100 per cent.

Fig. 5 also shows that with 18 ties per 33-foot rail the unloaded area of subgrade between adjacent ties becomes zero when the depth of ballast is increased from 6 inches to 14 inches, while with 20 ties per 33-foot rail it becomes zero with a ballast depth of 12 inches.

According to Johnson's formula for stone ballast, uniform distribution of subgrade loading will be obtained with 21⅓ inches of ballast for 18 ties per 33-foot rail and with 18⅔ inches of ballast for 20 ties per 33-foot rail.

Any consideration of the relief to be expected from decreasing the tie-spacing, increasing the depth of ballast or otherwise, should take into account the cost, and in this connection Table II is presented on page 214.

From this table it is seen that a reduction of tie-spacing from 22 inches to 20 inches increases the ratio of width of loaded to unloaded subgrade by 33⅓ per cent. at a cost of $464, $928, and $1856 per mile for single, double, and four-track lines respectively, while an increase of ballast depth of two inches (from 6 inches to 8 inches) increases this ratio by 52½ per cent. at the respective cost of $256.90, $507.23, and $1006.51 per inch additional ballast, or $513.80, $1014.46, and $2013.02 for the two inches of additional ballast. Whether the first or the second or a combination of both is best is therefore somewhat of an open question.

Some individuals and committees have recently recommended a ballast depth greatly in excess of previously existing standards and still greater than the ballast depths actually obtaining even on our densely travelled lines, without qualification dependent upon either the subgrades or the characteristics of the imposed loads.

TABLE II.

STATEMENT SHOWING COMPARATIVE COST OF INCREASING NUMBER OF TIES PER RAIL LENGTH (33 FEET) FROM 18 TO 20 AND COST PER INCH DEPTH OF PUTTING ADDITIONAL BALLAST UNDER STANDARD TRACK OF ONE OF OUR LARGER LINES.

Ties per mile spaced	Single track	Double-track	4-track
18 per rail length	2,880	5,760	11,520
20 per rail length	3,200	6,400	12,800
Additional ties	320	640	1,280
Cost per tie:			
1 tie	$0.90	Volume of 1 tie, 3.3 cubic feet.	
2 plates	.28	Cost of ballast, 75 cents per cubic yard.	
8 spikes	.11	Cost of laying ballast, 40 cents per cubic yard.	
	$1.29	Total cost of ballast in track, $1.15 per cubic yard.	
Credit account ballast displaced	.14		
Net cost per tie	$1.15		
Labor, placing tie in track	.30		
Cost per tie in track	$1.45		
Cost of additional ties in track		$464*	$928*	$1,856*
Full width of ballast base		164½″	324½″	644½″
Cubic yards per square inch section per mile equals 1.35				
Cubic yards ballast required		223.39	441.07	875.23
Cost of required-ballast in track, at $1.15		$256.9	$507.23	$1006.51

*Does not include labor cost of respacing present ties to make the insertion of additional ties possible, nor the cost of distributing the ties and ballast to point where placed in track.

To the writer it appears that the design of railroad track must be approached in the same way as the design of any mechanical parts. As a foundation it should be treated like any other foundation, and a study of its requirements, purposes, construction, and maintenance should be made. It must be designed to carry loads of certain individual magnitude, density and speed, etc., and must do this upon subgrade of given condi-

tions. With a sufficient amount of the right kind of data, it should be possible to combine the knowledge of the loads to be imposed with that of the subgrade conditions, and prescribe the most efficient and economical track construction, which, if it cannot be immediately provided, can be approached from year to year in connection with regular track maintenance work. Subgrade conditions vary materially within short distances, but with these conditions properly charted it should be a very easy matter, in bringing the condition of the track up to a desired standard, to concentrate effort upon those sections which are farthest from that standard and which will be located from tabulated or charted data or from the frequency of service failure.

Opinions of maintenance men vary greatly upon a majority of questions relating to track and track superstructure design, and practically none of these opinions is supported by such conclusive test or experience as will make early agreement or reconciliation possible. In the maintenance-of-way department dependable data are not being collected as in the motive power department, in which department much money has been, and is continually being, profitably spent to settle questions pertaining to the design and operation of both locomotives and cars, many of which questions are of less importance than some of those relating to track construction.

The writers upon maintenance-of-way subjects will have served a useful purpose if they succeed in focusing attention upon the comparative deficiency of experimental work in this field, for as soon as this deficiency is realized then work will be inaugurated which will, in a few years, elevate the science of track construction to its proper level. The condition of our tracks is now lagging behind requirements, and we cannot consistently hope for a better state of affairs unless some move along scientific lines is soon inaugurated. In the meantime, locomotive and car designers must "mark time," so far as increased loads and speeds are concerned.

While some investigations should necessarily be made under regular service, many can, nevertheless, be (and a few have been) carried out upon an experimental track of significant proportions. An experimental track was constructed a comparatively short time ago by the Prussian State Railroads at Oranienburg, Germany, and is being used to determine experimentally

the best construction. Dr. H. K. Hatt, of Purdue University, who visited this installation a few years ago, reported:

"It consists of an oval track two miles in circumference over which runs a train consisting of electric locomotive and cars. At about every fifty feet two vertical rail ends were sunk in the ground on each side of the track and clips riveted onto them to serve as a reference line, for measurement of track deformation. The service is considered as severe in one year as eight years on the main line. The cost of the roadbed and equipment is stated to have been $40,000.

"About a year before my visit the first track had become worn out and a new track consisting mainly of steel and beech ties had been set under service.

"Some of the elements which were being experimented with at Oranienburg may be listed as follows: Prussian standard steel ties with side ribs have been down one year in different forms of ballast. The evidences of derailment of cars were visible, but the steel ties were not sprung. The modern double steel tie was used at the joints.

"Various forms of anchorage of rails to ties were under experimentation. These anchors are found more necessary in steel ties than in the case of wood. The various forms of anchors seemed all to be effective, although the track as a whole had not been down long enough to give final results.

"The scarf joint appeared to be unsuccessful, inasmuch as the inner edge of the scarf sheared off at the edge, due to the wave motion in the rail.

"The records of traffic passing over this experimental track show that in 369 working days the number of kilometre tons was about six million. In the months of January, February, March, and April, in 1909, there were nearly seven million kilometre tons. The locomotive weighed 59½ tons and would pull a train of from 240 to 375 tons. The speed of the train was 60 kilometres per hour.

"At the time of my visit the plant was not in operation.

"The above notes were jotted down from conversation with one of the officials in charge at the time of the visit, and were not submitted to the railway authorities for confirmation. They should serve, therefore, to illustrate the programme of work rather than to present official conclusions."

The loads imposed upon this experimental track are insignificant in comparison with those which, for the results obtained to be of service, would have to be placed upon such a track in this country.

The writer would suggest that an experimental track be designed and constructed in the form of a figure 8, so that one loop could be operated while the other was being prepared for test. On this track, properly enclosed by fencing, etc., a motor, hauling any desired combination of cars, loaded with any desired axle loads, could be controlled from the office of an engineer of maintenance-of-way tests located in the centre of either of the loops, and in this way any combination of rails, fastenings, ties, joints, ballast, frogs, switches, signals, and safety devices could be tested.

The value of an ability, by this method, to rapidly test rails of different steels, under more scientific conditions, must be apparent when the amount of work done in settling rail questions during the last ten years is considered.

Such a plant, with its so general benefits, could be very properly be jointly constructed by interested railroads, perhaps under the direction of the American Railway Engineering Association, and tests on it carried out by some one of our educational institutions interested, in much the same way that motive-power department tests of various equipment furnished by different railroads, directly or indirectly through the Master Car Builders and Master Mechanics' Association, have for some years been conducted at Purdue University, Lafayette, Ind.

Panama-Pacific International Exposition, San Francisco, February 20–December 4, 1915.—The Department of Liberal Arts, of which Theodore Hardee has recently been appointed chief, announces that special efforts will be made to obtain a complete collection of exhibits of architecture, its allied arts and engineering. It will comprise drawings, models, and photographs of architecture and engineering in their various branches; plans followed in the improvement of rivers and harbors, water-works and sanitation; irrigation and roadmaking methods; specimens of artificial stone and kindred building material; processes used in testing structural materials, and special contrivances for safety, comfort and convenience in buildings. Detailed information may be had by addressing the Exposition.

Influence of the Metalloids on the Properties of Cast Iron. H: I. COE. (*Iron and Steel Inst.*, May, 1913.)—American washed iron was melted under charcoal in a graphite crucible, and when melted suitable alloys of the metalloids were added to form a series of 54 alloys, containing carbon 3.0, silicon from 0.4 to 2.24, manganese from 0.14 to 2.22, sulphur 0.11 to 0.45, phosphorus 0.30 to 2.88 per cent. Transverse strength, deflection, tensile, and hardness tests were made and the results tabulated. The conclusions are: (1) Silicon decreases the strength and hardness of cast iron, owing to its effect in promoting the decomposition of iron carbide. (2) Manganese to the extent of 0.5 per cent. softens silicious gray irons, owing to its effect on the condition of the carbon; the strength is increased by the addition of manganese. (3) The influence of sulphur is largely determined by the silicon present. Carefully controlled, it should be of considerable value to the iron founder in mixing his iron for any particular purpose. (4) In the absence of manganese, and with about 2 per cent. silicon present, very strong gray irons may be obtained if the percentage of sulphur be judiciously raised. (5) Phosphorus, up to about 1 per cent., is useful. It confers fluidity, slightly increases the strength, and also slightly diminishes the hardness of the metal. A higher percentage gives a hard brittle material. The influence of the metalloids on the pearlite formation was also investigated, and the cooling curves of six phosphoric irons are given. The paper includes nine microphotographs.

A New Use for Metallic Cobalt. ANON. (*Brass World*, ix, 6, 217.)—From an article in the *Ironmonger* it appears that cobalt may be largely used in steel manufacture. Steel experts in Sheffield are experimenting with a new grade of high-speed steel which contains a small proportion of cobalt in addition to tungsten, vanadium, and other usual ingredients. The effect of cobalt is to intensify the characteristic qualities of tungsten and vanadium and to impart to the tools increased speed and durability. Cobalt steel is already made in America and Germany, and some is offered in England at very high prices. The Sheffield steel makers will not offer this new steel to the engineering world till experiment has demonstrated beyond doubt its permanent commercial value, and the particular purposes for which it is adapted. A small quantity has been made in Sheffield, and some manufacturers have been asked to supply it. Cobalt is found in Ontario, and at present the supply is limited, but there is plenty of ore which could be mined if a regular demand arose. The current price is $2500 to $3000 per ton. Cobalt steel will be more expensive than the best vanadium steels, and it is not thought in Sheffield that it will supersede the present high-speed steels to any considerable extent, although it will be advantageous for various purposes. Experiments as to the effect of cobalt on carbon steel mixtures are being made.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

A CONVENIENT SECONDARY STANDARD OF RADIATION.

PENDING preparation of the full announcement, a preliminary note upon the secondary standard of radiation of the Bureau may prove of interest.

There has been heretofore no convenient standard of radiation analogous to the photometric standard now maintained at the national standardization laboratories. In order to attain a greater uniformity in rating its own radiometric work, and with the hope of placing radiometric work throughout the country upon a uniform basis, the Bureau of Standards has undertaken to maintain such a standard of radiation.

This is a secondary standard, in the form of well-seasoned carbon filament incandescent lamps, rated to give in absolute units the energy per square centimetre at a distance of 1 metre. The primary standard is the radiation from a uniformly-heated inclosure, the so-called black body. The coefficient of radiation (the Stefan-Boltzmann constant, σ, in the formula, $E = \sigma T^4$, where E = energy per square centimetre and T is absolute temperature Centigrade) is taken to be $\sigma = 5.7 \times 10^{-12}$ watt, or 1.36×10^{-12} gramme calorie per second. This value for the coefficient is based upon the most recent measurements, and may be modified in future years when more accurate determinations become possible. In the meantime it will be an advantage for all experimenters to work on the same basis, even though that basis may be 1 to 2 per cent. in doubt. This will be more satisfactory than the only simple basis of comparison now at hand, viz., the Hefner flame standard. Ångström found the radiation at 1 metre from the Hefner lamp (through a diaphragm having an opening 14 by 40 mm. placed 10 cm. from the flame) to be $S = 21.5 \times 10^{-6}$ gramme calorie per square centimetre; while a direct comparison with a black body, at the Bureau of Standards, gave $S = 23.4 \times 10^{-6}$ gramme calorie per square centimetre, when using a diaphragm having an opening of 14 by 40 to 14 by 43 mm. When the opening was 14 by 50 mm. the value

* Communicated by the Bureau.

was $S = 24.7 \times 10^{-6}$, and when no diaphragm was used the value was $S = 26.8 \times 10^{-6}$ gramme calorie per square centimetre.

The transfer from the primary to the secondary radiation standard,—*i.e.*, the comparison of the incandescent lamps with the black body,—was made by means of several of the Bureau of Standards form of bismuth-silver thermopile. The experimental error in the measurements on the incandescent lamps was of the order of 0.8 per cent. These measurements were made in the summer time, when there is greater temperature uniformity, permitting the operation of a thermopile in open air. In the autumn and winter it is usually quite impossible to operate delicate radiometers which are open to the air. Hence provision has been made for giving the value of the radiation from the standard lamp when the radiometer is covered with a glass window to avoid air currents.

If desired, the incandescent lamps can be rated both for candle-power and radiation, thus giving a standard of light and of radiation in one lamp.

In various investigations of photo-synthesis, of photo-electric phenomena, and in psychological problems, the intensity of the stimulus should be measured radiometrically by means of some simple radiometer,—*e.g.*, a thermopile with its auxiliary galvanometer. Knowing the area of the receiving surface exposed to the stimulus, the value of the stimulus in absolute units may be determined at once by exposing the thermopile to the standard of radiation. In this manner it will be possible to make more accurate and more uniform measurements of the stimuli acting in these various phenomena than have yet been obtained.

TESTING POTENTIAL TRANSFORMERS.

By H. B. Brooks,
Bureau of Standards.

THE commercial importance of instrument transformers has stimulated the development of accurate methods for the determination of their ratio and phase angle. These methods are suitable for the laboratory only. A method is wanted which, while giving all needed accuracy, can be carried out at the point

of installation, using commercial instruments and the ordinary supply voltage. Such a method of testing potential transformers is described in the present paper.

The primary windings of a standard transformer and the transformer to be tested are connected to the same supply. The secondary windings are connected in series so that their voltages are opposed. The small difference between the two secondary voltages is measured by means of an indicating wattmeter whose current coil is separately excited by a current in phase with the supply voltage. The ratio of transformation of the transformer under test may then be readily calculated.

By making the above test with the primaries connected to a two-phase circuit, a measurement of the difference of the phase angles of the two transformers may be made by exciting the current coil of the wattmeter from the second phase. If a two-phase circuit is not available, the test for phase angle may be made by exciting the wattmeter current coil from another phase of a three-phase circuit, and applying a simple correction factor.

A comparison of the above method and a standard laboratory method gave values for ratio agreeing to less than 0.1 per cent., and of phase angle within one minute.

A COMPARATIVE STUDY OF AMERICAN DIRECT-CURRENT WATTHOURMETERS.*

By T. T. Fitch,
Bureau of Standards.

This paper gives the results of numerous tests on six makes of American watthourmeters. The discussion is given under three headings: Performance Data; Details of Construction; Effect of Friction Losses.

Performance Data.—The load curve is shown to be a curve, which for the ordinary adjustment of the meter being correct at 10 per cent. and full load results in the meter being fast between 10 per cent. and full load and slow at over loads. The meters showed a variation of from 1 to 8 per cent. for a variation of voltage from 84 to 116 per cent. of the normal. For

* Scientific paper to appear in the *Bulletin of the Bureau of Standards*, vol. 10.

three-wire meters the two current elements were found to differ from equality by from 0.4 to 4.0 per cent. The range of starting coil adjustment at 10 per cent. load varied from 4 to 22 per cent. in rate of the meter for the different makers. The range of the magnet adjustment varied from 35 to 155 per cent. in change of the meter rate for the different makers. The meters were affected by short circuit on 220 volts, as shown by changes in the rate of from 0 to 34 per cent. The back electromotive force in the commutator meters at full load ranged from .07 to .19 volt and was about —0.1 per cent. per degree C., except for one meter which gave 0.25 per cent.

Effect of Friction Losses.—The friction torques due to the bearings, the brushes, the gearing, and the air were measured. The friction torques, with the exception of the air friction torque, are curvilinear functions of the speed.

Finally the load curve of the commutator meter is analyzed and its curvature shown to depend on the back electromotive force, the variation in the friction torque, and the change in rate caused by heating of the series coils. The discussion has not been extended to the mercury type meter in as complete form.

Influence of Sulphur on the Stability of Iron Carbide. W. H. HATFIELD. (*Iron and Steel Inst.*, May, 1913.)—An investigation in which three series of steels were employed, containing carbon 2.85 to 3.2 per cent., silicon 0.29 to 1.09, sulphur 0.01 to 0.85, and manganese 0.0 to 0.18 per cent., led to the conclusion that sulphur increases the stability of iron carbide, the action being chemical, not mechanical, as Levy suggested, and probably effected by a small percentage of sulphur associated with the carbide crystals; yet the action of sulphur is neutralized by manganese and also to a large extent by silicon.

A New Process for Coating Metals with Tin or Lead. ANON. (*Brass World*, ix, 6, 219.)—This patent was taken by Fritz Plathner and Nictor Dorn, of Berlin. For tinning, clean the metal from rust, scale, or grease, then mix two pounds tin powder and one pound zinc chloride to a paste with water or alcohol and spread over the metal. Then heat until the tin melts, and the whole surface will be covered with an adherent layer of tin. For coating with lead use the same method, only substituting powdered lead for tin. Ammonium chloride may be used instead of zinc chloride. Tin and lead powders are now commercial articles.

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(Stated Meeting of the Board of Managers, July 9, 1913.)

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THE RAILWAY TUNNELS OF NEW YORK CITY.

BY

ALFRED NOBLE, C.E., LL.D.

A CORRECTION.

Vol. CLXXV, page 383, line 7 from bottom, for "Hudson" read "Harlem."

" 384, in table, for "5166" read "5375;"
for "6676" read "6994;"
for "9102" read "9431."

LIBRARY NOTES.

Purchases.

ASKLING, C. W., and E. ROESLER.—Internal Combustion Engines and Gas Products. 1912.

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Festschrift W. Nernst zu seinem fünfundzwanzigjährigen Doktorjubiläum gewidmet von seinen Schülern. 1912.

GESCHWIND, L.—The Manufacture of Alum. 1901.

HOUSTOWN, R. A.—An Introduction to Mathematical Physics. 1912.

MCNICOL, D.—American Telegraph Practice. 1913.

NEWELL, F. H., and D. W. MURPHY.—Principles of Irrigation Engineering. 1913.

PATCHELL, W. H.—Applications of Electric Power to Mines. 1913.

REGNAULT, V.—Relation des expériences des machines à vapeur. 4 vols. 1847, 1862, 1870.

SELLEW, W. H.—Steel Rails. 1913.

TAYLOR, F. W.—On the Art of Cutting Metals. 3d edition. No date.

THORKELSON, H. J.—Air Compression and Transmission. 1913.

WATSON, W.—Advanced Textile Design. 1913.

Gifts.

Baldwin Locomotive Works, The, Record Nos. 73 and 74. Philadelphia, 1912 and 1913. (From the Works.)

Baylor University, Catalogue 1912–1913. Waco, Tex., 1913. (From the University.)

Canada Board of Railroad Commissioners, Seventh Report, March 31, 1912. Ottawa, 1913. (From the Commissioners.)

Canada Department of Mines: Annual Report on the Mineral Production of Canada for 1911. The Magnetic Iron Sands of Natashkwan. Ottawa, 1912 and 1913. (From the Department.)

Canada Department of Trade and Commerce, Report for 1912, Part 7. Ottawa, 1913. (From the Department.)

Carnegie Endowment for International Peace, Year Book for 1912. Washington, D. C., 1913. (From the Endowment.)

City and Guilds of London Institute, Report of the Council, 1913. London, 1913. (From the Institute.)

Columbia University: Publication No. 4 of the Ernest Kempton Adams Fund for Physical Research, Graphical Methods, by C. Rungl. Publication No. 6, Researches in Physical Optics, Part 1, by R. W. Wood. New York City, 1912 and 1913. (From the University.)

Connecticut Agricultural Experiment Station, 26th Annual Report, 1912. Hartford, 1913. (From the Station.)

Delaware College, Catalogue 1913. Newark, Del., 1913. (From the College.)

George Washington University, Catalogue, March, 1913. Washington, D. C., 1913. (From the University.)

Georgia Geological Survey, Bulletin No. 20, A Preliminary Report on the Mineral Springs of Georgia, by S. W. McCallie. Atlanta, 1913. (From the State Geologist.)

Laws of Vermont, 1912. Montpelier, 1913. (From the State Librarian.)

Nebraska State Railway Commission, Fifth Annual Report, 1912. Lincoln, 1912. (From the Commission.)

New York State Department of Health, Report on the Application of Ozone to Water Purification, by R. Spaulding. Albany, 1913. (From the Department.)

Société des Arts de Geneve, Comptes Rendus de l'exercice 1912. Geneva, Switzerland, no date. (From the Société.)

South Australia Geological Survey, Bulletin No. 2, and Review of Mining Operations, No. 17. Adelaide, Australia, 1913. (From the Survey.)

United States Commissioner of Education, Report for 1912. Vols. 1 and 2. Washington, D. C., 1913. (From the Bureau of Education.)

U. S. Department of Commerce: U. S. Coast and Geodetic Survey—Determination of Time, Longitude, Latitude and Azimuth, by W. Bowie. 5th edition. Washington, D. C., 1913. (From the Department.)

University of Arkansas, Catalogue 1912–1913. Fayetteville, Ark., 1913. (From the University.)

University of Michigan, Calendar 1912–1913. Ann Arbor, 1913. (From the University.)

University of Washington, Catalogue 1912–1913. Seattle, Wash., 1913. (From the University.)

Yale University, Report of the President, 1912–1913. New Haven, 1913. (From the University.)

BOOK NOTICES.

CARNEGIE INSTITUTION OF WASHINGTON, Publications.—The following volumes are announced for early publication:

No. 173. REICHERT, EDWARD T.—The Differentiation and Specificity of Starches in Relation to Genera, Species, etc.: Stereochemistry Applied to Protoplasmic Processes and Products, and as a Strictly Scientific Basis for the Classification of Plants and Animals. Quarto, in two parts. Part I. The Starch-Substance and Starch-Grain. Pages i–xviii + 1–342, 102 plates containing 612 photomicrographs, charts A–J. Part II. The Differentiation and Specificity of Starches. Pages i–xviii + 343–900 and 400 charts.

No. 180. JONES, HARRY C., and Collaborators.—The Freezing-point Lowering, Conductivity and Viscosity of Solutions of Certain Electrolytes in Water, Methyl Alcohol, Ethyl Alcohol, Acetone, and Glycerol, and in Mixtures of These Solvents with One Another. Octavo.

No. 186. BARUS, CARL.—The Diffusion of Gases through Liquids, and Allied Experiments. Octavo.

No. 190. JONES, HARRY C., and J. S. GUY.—Absorption Spectra of Solutions as Affected by Temperature and by Dilution: A Quantitative Study of Absorption by Means of the Radiomicrometer. Octavo.

No. 192. HUNTINGTON, ELLSWORTH, with contributions by CHARLES SCHUCHERT, A. E. DOUGLAS, and C. J. KULLMER. The Climatic Factor as Illustrated in Arid America. Quarto.

CHRONOLOGY OF AVIATION, by Hudson Maxim and William J. Hammer, New York. Reprinted from the *World's* Almanac for 1911. 23 pages, 8vo.

The Institute has received from Mr. Hudson Maxim and Mr. William J. Hammer 200 copies of the reprints which they have just issued of their "Chronology of Aviation," originally prepared for the *World's* Almanac of 1911. The data embrace the essential facts relating to aërial progress. In addition to a short historical *résumé*, are given tables of altitude records, speed records, quick-starting and slow-speed records, passenger carrying, English Channel and other over-water flights, cross-country flights, notable distance and duration flights. There are statistics relating to accidents and data relative to spherical and dirigible balloons or airships, etc. Of special interest are the tables giving the most important flights of the Wright Brothers.

Copies may be had without charge on application to the Secretary of the Institute.

PUBLICATIONS RECEIVED.

North Carolina Geological and Economic Survey, Joseph Hyde Pratt, State Geologist: The Coastal Plain of North Carolina, by Wm. Bullock Clark; Benjamin L. Miller, L. W. Stephenson, B. L. Johnson, and Horatio N. Parker. 552 pages. Illustrations, plates, maps, tables, 4to. Raleigh, State Printers, 1912.

U. S. Commissioner of Education, Report for the year ended June 30, 1912. 2 volumes. 8vo. Washington, Government Printing Office, 1913.

U. S. Bureau of Standards: Technologic Paper No. 12—Action of the Salts in Alkali Water and Sea Water on Cements, by P. H. Bates, A. J. Phillips, and Rudolph J. Wig. [November 1, 1912.] 157 pages, illustrations, plates, 4to. Washington, Government Printing Office, 1913.

The Transit, 1913. Edited by the Associated Students of Applied Science of the State University of Iowa. 50 pages, illustrations, portrait, 8vo. Iowa City, University, 1913.

Iowa State College of Agriculture and Mechanic Arts: Bulletin No. 31, Engineering Experiment Station—The Theory of Loads on Pipes in Ditches and Tests of Cement and Clay Drain Tile and Sewer Pipe, by A. Marston and A. O. Anderson. 181 pages, illustrations, 8vo. Ames, College, 1913.

U. S. Office of Public Roads: Circular No. 99—Process Reports of Experiments in Dust Prevention and Road Preservation, 1912. 51 pages, 8vo. Washington, Government Printing Office. 1913.

U. S. Bureau of Mines: Bulletin 51—The Analysis of Black Powder and Dynamite, by Walter O. Snelling and C. G. Storm. 80 pages, illustrations, plates, 8vo. Bulletin 54—Foundry-cupola Gases and Temperatures, by A. W. Belden. 29 pages, illustrations, plates, 8vo. Technical Paper 37—Heavy Oil as Fuel for Internal-combustion Engines, by Irving C. Allen. 36 pages, 8vo. Monthly Statement of Coal-mine Fatalities in the United States. April, 1913, with revised figures for preceding months, compiled by Albert H. Fay. 15 pages, 8vo. Washington, Government Printing Office, 1913.

Iowa State College of Agriculture and Mechanic Arts: Bulletin No. 30, Engineering Experiment Station—The Determination of Internal Temperature Range in Concrete Arch Bridges, by C. S. Nichols and C. B. McCullough. 101 pages, illustrations, plates, 8vo. Ames, College, 1913.

University of Wisconsin: Bulletin No. 529—Theory and Test of an Overshot Water-wheel, by Carl Robert Weidner. 136 pages, illustrations, plates, 8o. Madison, University, 1913.

Ignition of Mine Gases by the Filaments of Incandescent Lamps. H. H. CLARK and L. C. ILSLEY. (*U. S. Bureau of Mines Bull.* lii, 1913.)—Most of the experiments were made with a mixture of 91.4 per cent. of air and 8.6 per cent. of natural gas containing CH_4 (methane) 82, C_2H_6 (ethane) 16.4, N_2 (nitrogen) 1.5, and a trace of CO_2 (carbon dioxide). Tests were made with 1219 standard lamps and 234 miniature lamps. The naked filaments of all standard lamps, operated at rated voltage, will ignite the gaseous mixture used. All classes of standard carbon lamps will sometimes ignite the gas when the tips of the bulbs are broken off. The filament temperature of all classes of standard lamps, and of all but one class of miniature lamps, can be increased to such a degree that the lamps, when smashed, will ignite gas. When the bulbs of lamps burning at rated voltage were smashed, the results showed that 55- and 100-volt lamps of all candle-powers ignited gas under the conditions of the tests, and that 32- and 50-candle-power 55-volt lamps invariably ignited gas. The 8-candle-power 220-volt lamps gave no ignitions, and, in general, the percentage of ignitions obtained from lamps of given candle-power decreased as the voltage increased. When the tips of bulbs were broken the percentage of ignitions increased as the candle-power rating increased, and decreased as the voltage rating increased. Although no class of lamps gave 100 per cent. ignitions, all classes caused some ignitions.

Prize Offered by the German Bromine Convention. ANON. (*Chem. and Drug.*, May 17, 1913.)—A prize of $2500 is offered by the German Bromine Convention to the discoverer of a process or compound which will lead to a new and increased consumption of bromine. The existing German bromine factories have produced far more bromine than has been consumed, so a fresh field of use is urgently needed. Some of the conditions of the competition are as follows: The new discovery must represent a technical innovation, and must not adversely affect existing uses of bromine. The process must be practically applied within one year, at the latest, after the award of the prize. In the opinion of the jury, the process must lead to a considerable increase in the European consumption of bromine at a suitable price. Competitors must send in their processes not later than January 1, 1914, to the Deutsche Bromkonvention G. m. b. H., Leopoldshall-Stassfurt.

CURRENT TOPICS

Mortars and Concretes Mixed with Asphaltic Oils. A. TAYLOR and T. SANBORN. (*Proc. Amer. Soc. Civil Eng.*, xxxix, 355.)—Page's statements concerning oil-mixed concrete were subjected to a thorough investigation, and the following conclusions were reached as regards asphaltic oils: (1) Oil-mixed concrete containing 5, 10, or 15 per cent. of oil is more permeable under pressures of 20 to 60 pounds per square inch than ordinary concrete, and oil-mixed mortar containing 10 per cent. of oil is more permeable than plain mortar under pressure of 10 to 20 pounds per square inch. (2) Oil-mixed mortars containing up to 25 per cent. of oil show slightly less absorption of water than plain mortar, except that with the most viscous oils the mortar becomes more absorptive, and absorption is not an index of the permeability. The absorption decreases with the increase in the quantity of oil. (3) Both the tensile and the crushing strengths of oil-mixed mortars are considerably less than those of plain mortars, the strengths decreasing with the increasing quantities of oil, and the progressive deterioration with increase of oil being more marked in the case of crushing than of tensile strengths. (4) The strength decreases with the viscosity of the oils, and with the most viscous oils it requires considerably more water to keep a mixture at the normal consistence than is required in the fluid oil mixtures. (5) The relative decrease in strength with increasing quantities of oil in mortars is less in 50 days than in 28 days.

Density of Aluminum. F. J. BISLEE. (*Faraday Soc.*, May 7, 1913.)—The density of aluminum varies considerably, according to the previous treatment, and under certain conditions the density of the cast metal may exceed that of the worked metal, though the density of the worked metal increases again on annealing. The worked metal etched with hydrofluoric acid shows under the microscope a structureless surface, with flow lines in the direction of the work. Cast aluminum under similar conditions is very distinctly crystalline.

Moulding Aluminum Alloys. ANON. (*Brass World*, ix, 5, 168.)—For all aluminum alloys, both the light alloys in which aluminum is the chief constituent or aluminum bronzes, the moulding sand must be worked as dry as possible. Wet sand causes the metal to boil and thus produces dross. It is unnecessary to skin dry the mould, but the sand should be as dry as it can be worked and not rammed too hard.

Influence of Incombustible Dusts on the Inflammation of Gaseous Mixtures. ANON. (*Third Report of the Explosions in Mines Committee,* March 11, 1913.)—A detailed account of an investigation conducted mainly with the object of testing the accuracy of Abel's conclusions regarding the supposed action of incombustible dusts in promoting the inflammation of non-inflammable mixtures of fire-damp and air. Exception is taken to Abel's statement that flame can be propagated in a current of air containing as little as 3.5 per cent. of fire-damp and having a velocity of 200 feet per minute, or more, since the combustible portion of the fire-damp used in Abel's experiments was practically all methane, and the lower limit of inflammation of this gas when admixed with air is 5.6 per cent. according to Burgess and Wheeler, and between 5.0 and 6.7 per cent. according to all other experimenters. Abel's results were probably due to incomplete mixing of the fire-damp and air, for with apparatus adapted to produce "streaky" gaseous mixtures results similar to those recorded by Abel—but, it is suggested, misinterpreted by him—were obtained. By repeating Abel's experiments under the same conditions he employed, but with well-mixed gases, and measuring the rapidity with which flame spread through the mixtures in the absence and in the presence of various dusts in suspension, it was found that the inflammability of mixtures below the lower limit of inflammation, or of explosive mixtures, travelling at different rates, was decreased when an incombustible stone or calcined magnesia dust was present. This conclusion was confirmed by further experiments made in a horizontal iron gallery, in a vertical glass tube, and in a spherical explosion vessel. Incombustible dusts tend to decrease, rather than increase, the inflammability of gaseous mixtures containing them.

Acetin. EDITOR. (*Metal Industry,* xi, No. 5, 215.)—Acetin is a compound made by slowly boiling two parts glycerine and one part acetic acid for 20 minutes, allow to cool, and bottle. It is used with good results on old oil paintings that show a tendency to crack or curl. It is also used to remove the yellow stain from old celluloid piano keys or other celluloid articles.

Experimental Determination of the Regulation of Alternators. A. B. FIELD. (*Amer. Inst. Elect. Engin. Proc.,* xxxii, 599.)—The method of determining the regulation of an alternator from test results, which is incorporated in the Standardization Rules, is not accurate for low power-factors, as it fails to include the varying pole leakage or the ratio of armature reaction to reactive voltage drop. The effects of these are most marked at power-factor zero, and, as this is also the only power-factor at which a load regulation curve can usually be experimentally determined satisfactorily, it is advocated to base regulation determinations upon the power-factor zero load saturation and the no-load saturation.

Rock Salt in British Columbia. ANON. (*Oil, Paint and Drug Rep.*, May 19, 1913.)—An extensive bed of rock salt has been discovered on the Skeena River, about 45 miles from Prince Rupert. Five holes have been drilled, about a mile apart, and salt has been struck in every case at depths varying from 50 to 250 feet. About 8 tons of salt have been raised. The product is absolutely pure and of the best quality.

Rust-proof Coating for Iron or Steel. ANON. (*Amer. Mach.*, xxxviii, No. 18, 737.)—This new rust-proof coating is a paint that is applied to the surface of the article to be coated and is then baked. The ingredients are mixed in the following proportions: Linseed oil, 25 parts; calcium resinate, 36 parts; manganese borate, ½ part; lead acetate, 1 part; naphtha, 37½ parts; artificial graphite, 25 parts. These are mixed and applied to the metal by brushing, or dipping, or any other method. The article is then baked at 300° F. for 1 hour and 40 minutes. The coating is stated to be highly lustrous and resistant to corrosion. No other form of graphite gives satisfactory results.

Heat of Combustion of Diamond and Graphite. W. A. ROTH and H. WALLASCH. (*Ber.*, xlvi, 896.)—Diamond and various species of graphite, both natural and artificial, were burned in a bomb calorimeter with paraffin oil to aid the combustion. For 1 gramme of diamond the figure 7869 calories was obtained, agreeing with that of Berthelot and Petit. The mean figure for graphite was 7854 calories per gramme, though some specimens gave only 7830 to 7835 calories. This difference cannot be explained. Blast-furnace graphite gave 7855 to 7865 calories, much lower than Berthelot and Petit's figure, 7907 to 7902. Even these figures become 7923 calories if more recent values for the heat of combustion of naphthalene be taken.

Potential Waves of Alternating-current Generators. W. J. FOSTER. (*Amer. Inst. Elect. Engin. Proc.*, xxxii, 207.)—This article has a triple purpose: (1) To discuss briefly certain elements in design that affect the character of the potential wave. (2) To show the effect of load and operating conditions on the no-load wave. (3) To give illustrations of the potential waves—good, bad, and indifferent—of generators that actually supply the alternating-current systems throughout the country. There are ninety illustrations in all; a study of these, with the descriptions given, shows that the most perfect wave is obtained where the proper shading of the magnetic flux is attained either by shaping the poles, in the case of definite pole machines, or by the proper distribution of field winding in the case of cylindrical rotor machines, together with an irregular or more or less prime relation between the number of slots in the armature and number of poles.

Fuel Briquetting in the United States. E. W. PARKER. (*U. S. Geol. Survey.*)—The quantity of briquetted fuel made in the United States during 1912 at 19 plants was 220,064 short tons, valued at $952,261, as compared with 218,443 tons, valued at $808,721, in 1911. Seven of these plants used anthracite culm, 9 used bituminous or semi-bituminous slack, 1 used residue from gas manufactured from oil, 1 used anthracite culm and bituminous slack mixed, and 1 used peat. The best material for producing a smokeless product is anthracite culm, of which there is a plentiful supply in the anthracite region of Pennsylvania, and more is produced daily in the mining operations. It is hoped that in the near future the small sizes of anthracite that are now sold for raising steam, in competition with bituminous coal and at prices below the actual cost of production, will become more valuable as a raw material for the briquette manufacturer. The output of these small sizes from the breaking up of large coal exceeds 20,000,000 long tons annually, exclusive of 3,000,000 to 4,000,000 recovered annually from the culm banks by washeries. As briquetted fuel it should be worth $3 to $4 per ton. The cost of briquetting is $1 to $1.25 per ton.

Experience in European countries, and investigation at fuel-testing plants of the Geological Survey in St. Louis, and the Bureau of Mines, Pittsburgh, have shown that lignites can be successfully briquetted without any binding material, and that the most satisfactory binders for anthracite, semi-anthracite, bituminous, and sub-bituminous coals are coal-tar pitch, gas-tar pitch, and asphaltic pitch, or inexpensive cementing mixtures that are practically waterproof. Some manufacturers use no binder.

Porous Metals. R. GRIMSHAW. (*Metal Ind.*, xi, No. 5, 203.)—Herr H. J. Hannover has made microscopic studies of the various metals which have revealed some curious facts in reference to their pores. When an alloy of 96 parts lead and 4 parts of antimony was heated nearly to the melting-point and then allowed to cool, at first small, growing crystals separated, but at a temperature of 442° F. the contents of the "passages" between these also "set." When the alloy was reheated, the contents of the "canals" were the first to melt, the rest becoming fluid by further increase of heat. In a hot furnace the contents of the spaces between the crystals could be separated by centrifugal force, so that a porous lead plate resulted. The first experiments yielded a lead plate with crevices, but when the lead plate was surrounded by an iron pocket, having one side of brass wire cloth through which the melted metal could be thrown, it was possible to produce several porous lead plates having millions of microscopically small pores in a few minutes. Calculation showed that the surfaces exposed were 50 times as great as before the centrifugalling process. The invention of this porous metal is especially interesting and important to the accumulator industry.

The Corrosion of Aluminum. G. H. BAILEY, D.Sc. (*Eng.*, xcv, No. 2463, 374.)—After detailing numerous investigations on this subject, the following general conclusions are reached: (1) That, in general, the greater its degree of purity the less aluminum is acted upon by water and salt solutions. (2) That the corrosion is notably accentuated in presence of copper or sodium. (3) That where the percentage of silicon is higher than that of the iron the action is less pronounced in the case of water and acids, and more pronounced in salt solution. (4) That water and common salt solution, from which the air has been expelled, have no corrosive action. (5) That corrosion is accentuated (*a*) at high temperatures; (*b*) by the presence of impurities in the water, especially alkalies. (6) That unannealed metal is much more seriously corroded than annealed metal, doubtless owing to the unequal physical condition of the metal in the unannealed state. (7) That the results obtained by acting on aluminum with acids or alkalies afford no definite indication of its behavior in presence of water or aqueous solutions. Had it been possible to establish any parallel, the investigation of the corrosion of aluminum would have been much simplified, since the difficulties presented by the formation of suspended or adherent deposit would be eliminated.

Metallizing Siliceous Surface. ANON. (*Metal Ind.*, xi, No. 5, 200.)—*La Revue des Produits Chimiques* gives a process for putting a metal coating on siliceous surfaces, such as glass, pottery, etc. This method consists in treating the surface, which must not be enamelled nor varnished, with a solution of silver fluoride, and then exposing it to a current of illuminating gas. Later the article is exposed to a temperature of 50° C., and at that temperature to a current of carbon bisulphide. This causes the deposition of finely-divided metallic silver on the non-conducting surface. This deposit should be burnished, and then can be used as cathode in an electrolytic bath.

Thermal Electromotive Force of Tungsten and Molybdenum. E. F. NORTHRUP. (*Met. and Chem. Eng.*, xi, 45.)—Although tungsten and molybdenum oxidize at high temperatures, the author has been able to obtain the temperature-electromotive force curve of a thermo-couple composed of these two elements. In the experiments, temperatures were measured by the help of a platinum and platinum-rhodium thermo-couple. For the range 0° to 1000° C. the electromotive force was found to be given in microvolts by $E = 4.61t - 0.00436t^2$, and when the cold junction is at 0° C. the electromotive force is a maximum at 530° C. and is zero at 1060° C. In this range the current flows from tungsten to molybdenum at the hot junction. The author suggests that, if all samples are found to behave in the same way, the neutral point would be a convenient method of fixing the temperature, 1060° C.

Copper Production of the World. H. R. MERTON AND CO. (*Mining and Eng. World*, April 19, 1913.)—The output of copper in 1912 shows an increase of 15.2 per cent. over 1911. In spite of this the visible supplies in America and Europe decreased over 20,000 tons, indicating a consumption of approximately 1,024,500 tons, an increase of 11 per cent. over the previous year. The following table shows the production by countries in 1911 and 1912:

	1911.	1912.
United States	483,865	554,835
Spain and Portugal	50,930	58,930
Russia	25,310	33,010
Boleo	12,165	12,450
Other parts of Mexico	48,740	58,395
Japan	55,000	65,500
Australia	41,840	47,020
Canada	24,930	34,710
Chili	25,595	37,305
Mansfield	20,520	20,180
Miscellaneous	83,025	82,150
Total	871,920	1,004,485

Kukui Oil. E. V. WILCOX. (*Oil, Paint and Drug Rep.*, March 24, 1913.)—The nuts of the Kukui tree, which is found in several of the Oceanic Islands and also in parts of the West Indies, Brazil, and Florida, yield an oil, variously known as kukui oil, kekune oil, candlenut oil, walnut oil, and artists' oil. Probably about 15,000 acres in Hawaii are covered with the trees. If the nuts were systematically gathered an annual yield of about 2,375,000 gallons of oil should be obtained.

Granular Chromium as a Resistance Material for Electric Heating. O. DONY-HENAULT. (*Comptes Rendus*, clvi, 66.)—Granular chromium, tungsten, or molybdenum, etc., prepared by the thermite process, can be used for electrically heating crucibles, tubes, etc. The granules do not conduct at once; but they can, like coherers, be made conductors of electricity by passing a spark discharge in their neighborhood, or by coating them with Acheson's graphite, or by heating the metal with a Bunsen burner, when the current between the carbon electrodes at 110 volts will suddenly start; the graphite also seems to act by the heat generated in it by the current. To heat a crucible, a hollow is made in magnesia and filled with the granular metal, so that a layer of 2 to 4 mm. thick of metal surrounds the crucible; the current is introduced by carbon brushes and rings. Quartz tubes are jacketed with the metallic grains.

The "Pyro" Boiler-cleaning System. ANON. (*Eng.*, xcv, No. 2463, 377.)—The difficulty of satisfactorily removing hard scale from the interior of steam boilers has induced the expenditure of much ingenuity and from time to time of large sums of money on the part of investors. These attempts met with more or less success, but, notwithstanding that, the old practice of hand-chipping with hammers is still usually adopted. The latest scientific method of removing scale has left the beaten track, and instead of applying scraping and percussion, as is usual, heat in a very intense form is utilized. The apparatus was brought out by Mr. Adolph Schror, and the process has been termed the "pyro" boiler-cleaning system. The plant required is extremely simple, consisting of an oxyacetylene blow-pipe with two or three jets, a portable acetylene generator, and a steel cylinder of compressed oxygen, together with the necessary length of flexible tubing. When any scale is to be removed, all that is necessary is to play upon it with the blow-pipe flame for a few minutes (time depends on the thickness of scale) until the scale cracks and falls off, due to the rapid expansion under the intense heat. The operation is easier if the scale is slightly damp. In an actual operation it has been found satisfactory. Care has to be taken to prevent the flame from playing on the bare plate for any length of time. When flat pieces of hard scale, some of them $\frac{5}{8}$ inch thick, were held on the bare hand, with a piece of white paper between, and the flame was directed on the scale, this fell to pieces, while the paper was not scorched nor the hand burned. A distinct feature of the system is that it can be easily applied to almost inaccessible parts of a boiler, where hand-chipping is quite impossible. After cleaning off the scale the inside of the boilers is painted with "corrosanti" paint, which, it is claimed, preserves the plates.

Decrease of Speed of Electrified Particles on Passing through Matter. N. BOHR. (*Phil. Mag.*, xxv, 10.)—The theory of the decrease of velocity of moving particles in passing through matter is expressed in the form that the rate of the decrease depends on the frequency of vibration of the electrons in the atoms of the absorbing material. It is shown that the absorption of α-rays in the lightest elements can be calculated from the information about the number and frequencies of the electrons in the atoms, which we get from the theory of dispersion, and that the values are in good agreement with experiment. For elements of higher atomic weight it is shown that the number and frequencies of the electrons we must assume, according to the theory, in order to explain the absorption of α-rays, are of the order of magnitude to be expected. It is further shown that the theory can account for the form of the relations between the velocity of the rays and the thickness of matter traversed, found by experiments with kathode-rays and β-rays. Adopting Rutherford's theory of the constitution of atoms,

it seems that it may be concluded with great certainty, from the absorption of α-rays, that a hydrogen atom contains only one electron outside the positively-charged nucleus, and that a helium atom contains two electrons outside the nucleus.

The Nature of Corona and the Dielectric Strength of Air. F. W. PEEK, JR. (*Gen. Elect. Rev.*, xv, 781.)—A continuation of a previous work. It is shown first that the losses, established by calculation on the author's formulæ, agree with values actually measured on working lines, with special reference to Faccioli's and Hendricks' work. Then follows a section dealing with stroboscopic work, and the difference between the positive and negative halves of the alternating-current wave. The third section gives a theory explaining the apparent greater dielectric strength of air round small conductors as compared with that round larger conductors. The concluding paragraphs have reference to the limits which are likely to be set to high-voltage transmission by corona losses.

Molecular Phenomena not in Agreement with Thermodynamics. M. V. SMOLUCHOSWSKI. (*Phys. Zeitschr.*, xiii, 1069.)—The Brownian molecular motions, the opalescence of gases in the critical state, the blue of the sky, and some other phenomena have led to a decision in favor of a real kinetic theory of gases as distinct from the traditional purely phenomenalistic thermodynamics. The difference is most clearly brought out by a definition of the steady state. This used to be considered to be the state of minimum potential, to which an undisturbed body gradually approximates. The molecular kinetic view, on the other hand, admits the probability of continual fluctuations about this state, and of occasionally serious departure from it. The Brownian motions of particles denser than the containing liquid lead to a distribution according to a barometric exponential law, instead of a collection of all the particles at the bottom of the vessel. The work of Perrin on liquids and of Ehrenhaft and de Broglie on gases has fully confirmed this. The rule that the mean square of the concentration equals the reciprocal of the molecules contained in it has been successfully applied by Svedberg to gamboge emulsions and colloidal gold solutions. It is shown, too, that opalescence is due to the fluctuations in density of a gas.

Modifications of Iron below 700° C. F. ROBIN. (*Rev. de Métallurgie*, ix, 1083.)—A list is given of the points of singularity revealed in iron up to 700° C. A review of the evidence based on mechanical, magnetic, thermo-electric, and sonority tests made by numerous workers points to the existence of two allotropic changes in iron, one between 100° and 250° C. and the other between 400° and 500° C.

Monel Metal. R. H. GAINES. (*Chem. News*, cvii, 28.)—A synopsis is given of the methods of manufacture, the reduction having been so perfected as to give a product of very uniform composition, different analyses of different varieties only varying between the limits: Nickel, 67.55 to 69.54 per cent.; copper, 26.25 to 27.53 per cent.; carbon, 0.17 to 0.44 per cent., and iron, 2.07 to 3.33 per cent. In forged or rolled metal the manganese varies from 1.26 to 1.82 per cent., and the silicon from 0 to 0.37 per cent., while in cast metal the manganese varies from 0.09 to 0.49 per cent., and the silicon from 1.08 to 1.41 per cent. Variations in mechanical properties have little relation to variations in composition. Carbon appears to strengthen the alloy; iron hardens, whitens, and increases the strength, but appears to reduce the elastic limit. Silicon and manganese do not materially affect the physical properties, but manganese may correct the action of sulphur, which is probably present. The alloy resembles nickel in color, it machines well, and takes a high polish and retains it indefinitely. It melts at 1360° C.; has a specific gravity of 8.87 and a hardness number of 20 to 27 on the Shore scale. It is magnetic and absorbs carbon, which can exist in it both free and combined. Compared with nickel and copper its mechanical properties are:

	Copper, rolled.	Nickel, rolled.	Monel metal.		
			Cast.	Rolled.	Annealed.
Tensile strength, pounds per square inch....	34,000	75,500	85,000	100,000	110,000
Elastic limit, pounds per square inch....	18,000	21,000	40,000	50,000	80,000
Elongation, per cent. in 2 inches	52	43.9	25	30	25
Contraction, per cent.....	57	57	25	50	50
Modulus of elasticity.....	.....	.....	22,000,000 to 23,000,000		

Monel metal resists corrosion by sea-water, superheated steam, and chemical solutions about as well as Parson's manganese bronze, phosphor bronze, and Tobin bronze. There is no difficulty in forging and rolling it, but on account of its high melting-point and power of dissolving gases special precautions are needed in making sand castings, somewhat similar to those necessary for making steel castings. These uses are suggested: pump cylinders for sea-water, propellers, rudders, mining screens, valves, and plumbing fixtures subject to corrosive influences. Sheets of monel metal are largely used in America for roofing purposes.

Nomenclature of Micro-constituents and the Micro-structures of Steel and Cast Iron. H. M. HOWE and A. SAUVEUR. (*Rev. de Métallurgie*, ix, 983.)—Division into metarals and aggregates is adhered to, and only generally-accepted principles and theories have been considered. First, there is the liquid iron, which forms austenite, cementite, and graphite during solidification. During the transformation of austenite, martensite, troostite, and sorbite are formed as intermediate products; the final products being ferrite and pearlite. Other and rarer constituents are: lederburite (Wüst)—the austenite cementite eutetic; ferronite (Benedicks)—iron containing about 0.27 per cent. of carbon; steadite (Sauveur)—the iron-iron phosphide eutectic; and the three transition products, harenite (Arnold), osmondite (Heyn), and troosto-sorbite (Kourbotoff). The latter is falling into disuse, while osmondite is described as the limiting phase between troostite and sorbite. Manganese sulphide is also included as a micro-constituent of steel.

Electron Theory of Thermo-Electricity. O. W. RICHARDSON. (*Phil. Mag.*, xxiv, 737.)—The difference between Bohr's results and the author's may arise from neglecting to include effects due to a possible difference in the rate of transference of kinetic energy by an electric current in different materials. In this paper the former calculations are extended to include these effects. It seems probable that effects due to chemical action ought to be included, and recent experiments by Pring and Parker on carbon, and by Fredenhagen on sodium and potassium, strengthen this probability. Richardson thinks that electronic emission may be conditioned by chemical action, but considers that there is considerable evidence in favor of the view that there is an emission of electrons from her conductors which is independent of chemical action.

Electric Furnace for Experiments in Vacuo at Temperatures up to 1500° C. R. E. SLADE. (*Roy. Soc. Proc.*, Ser. A, lxxxvii, 519.)—This furnace consists of a platinum tube 2 cm. in diameter and 17 cm. long, with walls 1 mm. thick. This was mounted in water-cooled brass terminals at the ends. By means of a current of 350 to 500 ampères at ¾ volt passed through the tube, the interior of the latter attained a temperature of 1400° to 1500° C. The tube is fitted in an asbestos box filled with magnesia, and the whole furnace is placed under an iron dome. Arrangements are made for evacuating the furnace, for reading the internal pressure, for measuring the temperature by means of a thermo-element, etc. Diagrams are given.

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